THE IRRIGATION WORKS OF INDIA.

THE IRRIGATION WORKS OF INDIA

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"Behold, I will do a new thing; now it shall spring forth; shall ye not know it? I will even make a way in the wilderness, and rivers in the desert."—ISAIAH xliii. 19.

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PREFACE.

SINCE the first edition of the Book appeared in 1893, the area watered by Irrigation Works controlled by Government in India has increased by fifty per cent. The increase is partly due to the development of old works, and partly to the construction of new ones. The original book included some description of the Irrigation Works of Egypt. This has been almost entirely omitted in this revised edition, mainly because a description of Indian works afforded more than sufficient material. The difficulty has been to compress it within a reasonable space. The main features of the book remain the same, but it is altered in form. The chief object of this alteration is to afford space for the Plates on the page of the book itself, and to avoid the inconvenience caused by a large number of folded Plates.

The Government of India and the Governments of the various Provinces have kindly given me facilities which have enabled me to correct and amplify the book, and have been good enough to print for me some of the maps which are included in it. I have been placed in direct communication with almost every Chief and Superintending Engineer of Irrigation Works in India. All—or almost all—have given me assistance, and I would express my obligations to them without attempting to specify those to whom I am more particularly indebted.

Descriptions of works have, in some cases, been taken almost *verbatim* from reports and notes supplied by the local officers. As far as possible I have indicated the source of the information by footnotes, but I fear that some may have been omitted.

All the unsold copies of the first edition of the book were destroyed by fire at the publishers, and it has consequently been out of print since December, 1903. The delay in issuing this edition has been caused by the fact that Indian irrigation officers are busy men, and it has taken time to collect the information required for its revision.

The original work found its way to many of the Colonies and elsewhere, and I trust it has been useful. The record of the great Irrigation Works of India and of the benefits which they confer on the people cannot but tend to display the true beneficence of British rule in the great continent which is so important a portion of the Empire.

I have appended a list of books and publications which students of Irrigation will find interesting. Many of them are out of print. They can be seen either at the Library of the India Office or at the Institution of Civil Engineers in London.

R. B. B.

July, 1905.

TABLE OF CONTENTS.

CHAPTER I.

GENERAL AND DESCRIPTIVE.

Necessity for Irrigation in the Tropics—Inequalities of Rainfall—Area Irrigated in India—Mechanical Methods of Irrigation—Well Irrigation—Geological Considerations—Tanks and Reservoirs in different Provinces—Karezes in Baluchistan—Inundation Canals—The Indus—Perennial Canals—Progress of Irrigation Works in India—Utilisation of Water Supply—Storage Works—Canal Extension in the Punjab. Pages 1 to 24

CHAPTER II.

INUNDATION CANALS.

Heads of Inundation Canals—Col. Tremenhere's experience on the Indus—Rise and Fall of Indus Flood—Lift Irrigation on Inundation Canals—Superiority of River Water to that of Wells—Crops grown in the Punjab and Sind—Inundation Canals in Egypt. . . . . Pages 25 to 29

CHAPTER III.

SILT.

Nature of Silt—Proportion of Silt in different Rivers—Quantity of Material carried to the Sea by the Indus and the Nile—Silt in Suspension—Analysis of Silt—Shingle Deposits in the Ganges and Jumna Canals—Heavy Silt Deposits in Sone Canals—Sand carried into the Canal by Flow along the Bed—Silt in the Sone and Sirhind Canals—Flushing out Silt in Canals of Upper India—Canals choked by Drifting Sand—Surface Draught preventing Silt—Flushing Canals—Scouring Silt—Kennedy's Method—Silt in Baree Doab Canal—Brick and Stone Groynes to prevent Silt—Silting Checked by Uniform Velocity. . Pages 30 to 49

CHAPTER IV.

FLOW-OFF FROM CATCHMENT AREAS. EVAPORATION, ABSORPTION.

Necessity for Reservoirs—Reservoirs liable to fail when most required—Maximum Discharge from a Catchment—Coefficients in Dickens' and Ryves' Formulæ—Maximum Discharge from Small Catchments—Average Flow off a Catchment—Flow-off dependent on Condition of Catchment—Loss by Evaporation and Absorption in Reservoirs—Absorption checked by Silt—Instances of Loss of Water in Canals by Evaporation and Absorption . . . . Pages 50 to 69

CHAPTER V.

STORAGE WORKS, RESERVOIRS, TANKS.

Madras Tanks—Rushikulya Project—Periyar Project—Cross Sections of Various High Masonry Dams—Marikanave Reservoir—Nira and Mutha Canals—Bhatgarh Reservoir—Conditions of Design of Bhatgarh Dam—Weight of Concrete in Bhatgarh Dam—Under-sluices of Bhatgarh Dam—Waste Weirs of the Bhatgarh Reservoir—Head-works of the Nira Canal—Tanks in Rajputana—Earthen Embankments—Grass Revetments in Tanjore—Statistics of the Principal Tanks in Bombay—Statistics of Rajputana Tanks . . . . Pages 70 to 96

CHAPTER VI.

PERENNIAL CANALS IN DELTAIC TRACTS. EMBANKMENTS.

Formation of Deltas—The Mahanuddee Delta in Orissa—Decrease in Waterway in Deltaic Streams—Embankments necessary in Deltaic Projects—Limits to Embankments in Deltas—Increase in Flood Levels due to Embankments—Deltaic Tracts at Confluence of Rivers—Reduction in Waterway of the Sone River as it approaches the Ganges—The Floods of the Gunduk—Drainage essential in Deltaic Projects—Embankments in Deltaic Tracts—Damage due to Embankments—Effect of Embankments in increasing or decreasing Discharge—Disadvantages of Embankments . . . . . Pages 97 to 106

CHAPTER VII.

GENERAL NATURE OF HEAD-WORKS.

Purposes of Head-works—Influence which Silt has with reference to Site and Design—Oblique Weirs and those at Right Angles to the Axis of the Stream—Head-works in Deltaic Tracts—Old Weirs—The Grand Anicut in Madras—Classes of Indian Weirs—Dangers to River Weirs—Onward Flow of the Materials forming the Bed of a River—Increase of Level of River Beds above Weirs—Sluices insufficient to check Deposits above Weirs—Currents induced by Accretions in a River Bed above a Weir—Parallel Currents along the Face of Diagonal Weirs—Retrogression of Levels . . . . . . Pages 107 to 113

CHAPTER VIII.

HEAD-WORKS IN ROCK AND BOULDERS.

Bandharas in Kandesh—Soonkesala Weir—Betwa Weir—Afflux of 6 or 8 feet on Betwa Weir—Under-sluices of the Betwa Weir—Head-sluice of the Betwa Canal—Head-works Mandalay Canal—Ravi Weir of the Bari Doab Canal—Training Works on the Ravi—Site of the Head-works of the Bari Doab Canal not well selected—Under-sluices of the Ravi Weir—Under-sluice Gates of Ravi Weir—Head-sluice of Bari Doab Canal—Head-works of the Eastern and Western Jumna Canals—Under-sluices of the Jumna Weir—Head-sluice of the Western Jumna Canal—Jumna Weir—Regulation of Eastern Jumna Canal—Faizabad Dam—Khara Spur at head of E. Jumna Canal—Ganges Canal Head-works—Temporary Dams at head of Ganges Canal . . . . Pages 114 to 137

CHAPTER IX.

HEAD-WORKS IN CLAY AND COARSE SAND.

Sidhnai Canal Weir on the Ravi River—Weirs on the Mahanuddee in Orissa—Centre Sluice of Mahanuddee Weir—Mahanuddee Under-sluices—Panchkoorah Weir—Breach in the Mahanuddee Weir—Weirs in Deep Sand—Kistna Weir in Madras—Godavery Weir—Coleroon Weir—The Sone Weir in Bengal—Closing Centre Sluices of Sone Weir—Under-sluices of the Sone Weir—Sirhind Canal Weir across the Sutlej . . . . Pages 138 to 156

CHAPTER X.

HEAD-WORKS IN FINE SAND AND SANDY MUD.

Weirs in fine Micaceous Sand—Narora Weir across the Ganges—Protective Works above the Narora Weir—Narora Under-sluices—Under-sluice Gates of the Narora Weir—Head-sluice of the Lower Ganges Canal—Scouring Escape of the Lower Ganges Canal—Head-works Chenab Canal—Chenab Weir—Rosetta Weir—Chenab Under-sluices—Head-works of the Jhelum Canal—Jhelum Weir—Under-sluices of the Jhelum Weir—Okla Weir of the Agra Canal—Under-sluices of the Narora Weir—Protective Works at the Okla Weir—Comparison of Deep and Shallow Foundations—Percolation below Weirs—Barrage across the Nile below Cairo—Reconstruction of the Nile Barrage—Zifta and Assyut Barrages—Cost of Indian Head-Works . . . . Pages 157 to 179

CHAPTER XI.

GATES OF UNDER-SLUICES AND WASTE WEIRS. MOVABLE DAMS.

Principles of the Construction of River Weirs—Central Sluices in a Weir of Doubtful Value—Size of Under-sluices—Baulks and Needles in Under-sluices—French Shutters in Orissa and Midnapore—Hydraulic Break Shutters of the Sone Weir—Hydraulic Opening Gear—Fouracres' Double Tumbler Shutter—Under-sluice Gates in Upper India—Gates on the Barrage at Cairo—Counter-balanced Gates in Madras—Under-sluice Gates of the Bhatgarh Dam in Bombay—Automatic Waste Weir Gates—Gates of the Bhatgarh Waste Weir . . . . Pages 180 to 201

CHAPTER XII.

REGULATORS, HEAD-SLUICES, ESCAPES, CANAL FALLS, WEIRS, BRIDGES.

Head-sluices or Regulators—Head-sluices liable to be "blown up"—Head-sluice Shutters—Head Regulator Chenab Canal—Head Regulator Trebeni Canal—Regulators, Regulation by Needles—The Egyptian System of "verticals" (or needles) and "horizontals"—Escapes—Egyptian Escapes—Pooling below Escapes, and methods for preventing it—Qushesha Escape, carrying 80,000 cubic feet a second—Canal Falls or Weirs—Grating and "Ogee" Falls—Rapids on the Bari Doab Canal—The Cascade Rapid—Canal Falls in Southern India—Impounded Water in Canal Reaches—Notch Falls on the Sirhind Canal—Best form for Notches—Canal Bridges . . . . Pages 202 to 227

CHAPTER XIII.

CROSS DRAINAGE WORKS, SUPER-PASSAGES, AQUEDUCTS.

Drainage crossing Canals—Inlets and Escapes—Rutmoo Torrent, Ganges Canal—Danger of Canal being blocked—Budki Super-passage—Siswan Super-passage—Solani and Kali Nuddee Aqueducts—Aqueducts in Bengal—Thapangaing Aqueduct—Ravi Syphon—Steel-tube Syphons—Syphon Aqueducts—Burra Bubsa Syphon—Velocities in Syphons—Difficulties connected with Syphons in Flat Drainages Pages 228 to 250

CHAPTER XIV.

NAVIGATION, LOCKS.

Canals for Navigation only—Silting in Tidal Canals—Canals for both Irrigation and Navigation—Combined System of Irrigation and Navigation not financially successful—Navigation in India generally—Navigable Rivers in Bengal—Relative Position of Lock and Weir—Cracking and Failure of Lock Walls—Apjohn's Theory of Settlement of Foundations in the Deltaic Soil of the Ganges—Pressures on Lock Walls—More recent Designs adopted in Bengal—Equality of Pressure on Foundations desirable during construction—Width of Base of Lock Walls—Lock Gates and their Fittings . . . . . . Pages 251 to 269

CHAPTER XV.

DUTY OF WATER.

Definition of the "Duty" of Water—Duties Expressed in Different Forms—"Base" of Duties—Duties in Khareef and Rabi Seasons—Duty "at the head" and Duty "utilized"—Duties in Canals and Distributaries—Variations in Duties due to Soil, &c.—Great Variation in Duties—Low Duties may display waste—Duties during Periods of Pressure—Duties for Rice Irrigation in Bengal and Madras—Duties for Rabi Irrigation—Experiments on Duties—Duty of Water in Egypt—Gauging Canals to ascertain Duties—Duties largely affected by care in distribution—Irrigation by Rotation or "Tatils"—Trouble and perseverance required to establish "Tatils"—An Example of Tatil Tables . . . . Pages 270 to 285

CHAPTER XVI.

THE ALIGNMENT OF CANALS AND DISTRIBUTARIES. DESIGN OF CHANNELS.

Alignment of Canals on the Watershed—Contoured Plan of the Irrigable Area—Velocity to be Allowed in Canals—Dimensions of Canals—Restriction of Irrigated Area—Best Forms of Channel—Canals in Side-long Ground—Retaining Walls, Kurnool Canal Banks—Cost of Main and Branch Canals—Design of Distributaries—Discharging Capacity of Distributaries—Silt Berms in Distributary Channels—Difficulties connected with Main Channels for Rice Fields—Cost of Distributaries per Mile and per Acre Irrigable—Outlets from Distributaries—Regulation of the Size of Outlets—Drainage of Irrigated Tracts—Cost of Drainage Works . . . . Pages 286 to 301

CHAPTER XVII.

REVENUE AND ADMINISTRATION.

Irrigation Revenue—Miscellaneous Revenue—Consolidated Rate—Occupier's Rate—Owner's Rate—Enhancement of Land Revenue due to Canals—Administration—Assessment of Irrigation Revenue—Cost of Revenue Management—Cost of Working Expenses . . . . Pages 302 to 307

CHAPTER XVIII.

COST OF INDIAN IRRIGATION WORKS, AND THE FINANCIAL AND AGRICULTURAL RESULTS OBTAINED FROM THEM.

General Classification—Capital Cost of Productive Works—Major Works (A)—Gross Profit on Productive Works—Progress of Productive Works—Protective Works—Major Works (B)—Minor Works (A)—Profits from Minor Works (A)—Extent of Minor Works (A)—Minor Works (B)—Agricultural Results—Political Value of Irrigation—Developments of Irrigation in India—Protection from Famine—New Projects—Gross Revenue derived by Government . . . . Pages 308 to 321

LIST OF FOLDED PLATES.

FACING PAGE

Map of the Irrigation Works and Rainfall of India 6

Map of the Irrigation Canals in the Punjab 10

Map of the Orissa Canals 16

Map of the Irrigation Canals in the United Provinces 18

Map of the Sone Canals 24

Maladevi Tank Project 96

The Sone Weir 150

Under-sluice Gates of the Chenab Weir 190

Escape on the Arrah Canal 214

Chitpore Lock in Calcutta 258

LIST OF PHOTOGRAPHIC ILLUSTRATIONS.

	FACING PAGE
Surface Supply Inlet, Sone Canals	36
Myapur Regulator at the Head of the Ganges Canal	36
The Lake of the Periyar Reservoir from below the Dam	72
The Fuleli Canal at Hyderabad in Sind	72
Site of Marikanave Dam before Commencement of Work	78
Marikanave Dam under Construction in 1900	78
Lake Whiting on the Nira Canal, Bombay	86
Lake Fife on the Mutha Canals, Bombay	86
Panchkoorah Weir, Midnapore Canal	110
Narora Weir at the Head of the Lower Ganges Canal	110
Head Regulator and Under-sluices of the Mandalay Canal	120
Under-sluices of the Madaya Weir on the Mandalay Canal	120
Under-sluices of the Madhopur Weir, Bari Doab Canal (Up-stream)	126
Under-sluices of the Madhopur Weir, Bari Doab Canal (Down-stream)	126
Fyzabad Dam, Eastern Jumna Canal	128
Head Bunds on the Ganges Canal, looking Up-stream	128
Lifting Under-Sluice Shutters, Panchkoorah Weir	146
Under-sluices, Midnapore Weir	146
Under-sluices of the Rupar Weir at the Head of the Sirhind Canal	154
Under-sluices of the Jhelum Weir	154
Under-sluices of the Sone Weir	186
Under-sluice Gates, Sone Weir	186
Counter-balance Lift Gates, Coleroon Weir	194
A Needle Regulator on the Fuleli Canal in Sind	194
Grouped Automatic Waste-Weir Gates, Lake Fife, Bombay	198
Single Automatic Waste-Weir-Gates, Lake Whiting, Bombay	198
Head Regulator of the Sirhind Canal at Rupar	206
Head Regulator of the Jhelum Canal	206
A Fall on a Bengal Canal	216
Reri Bridge and Fall, Eastern Jumna Canal	216
Budki Super-passage on the Sirhind Canal	230
Siswan Super-passage on the Sirhind Canal	230
Kerai Aqueduct, Midnapore Canal	240
Ranipur Super-passage, Ganges Canal	240
Solani Aqueduct on the Ganges Canal	250
Level Crossing at Dhanauri on the Ganges Canal	250
Navigating the Ganges in 1844	254
Navigating the Ganges in 1904	254
A Navigable Canal, Sone Canals	262
Officers' Inspection Boat, Midnapore Canal	262

LIST OF PLATES AND ILLUSTRATIONS.

CHAPTER I.

	PAGE
The Persian Wheel	3
The *Mote*	3
The *Lât* or *Picottah*	3
The *Shadouf*	4
The Basket	4
The *Doon*	4
The Barur Tank Project	8
Kistna Delta System	14
Godavery Delta System	16
Sanctioned Project for New Canals in the Punjab	23

CHAPTER II.

Off-take of Inundation Canals	25
Diagram of Ordinary Floods of the Indus and the Nile	27

CHAPTER III.

Shutters of Sirhind Canal Head-sluice	40
Surface Supply Inlet, Sone Canals	40
Silt-testing Bucket	41
Diagram showing Maximum and Minimum Silt Slopes, Sirhind Canal	41
Silt Fleet for Flushing on the Sirhind Canal	43
Side Borrow Pits	44
Groynes on the Ibrahimiah Canal	47
Heads of Egyptian Inundation Canals	49

CHAPTER IV.

Diagram of Monsoon Rainfall at Jubbulpore	60
Diagrams showing Approximate Run-off for various Rainfalls	62

CHAPTER V.

Map of Suruliyar Minor Basin	70
Map of Rushikulya Reservoir System	72
Periyar Reservoir System	74
Longitudinal Section of Periyar Dam and Escapes	75
Cross Section of Periyar Dam	76
Cross Sections of Indian Masonry Dams	76
Marikanave Dam—Plan and Sections showing Foundations	78
Longitudinal Section of Site of Marikanave Dam	79
Profile of Marikanave Canal	80
Lake Fife and Lake Whiting on the Nira and Mutha Canals	81

CHAPTER V. (*continued*).

	PAGE
Section of Bhatgarh Dam	82
General Plan, Bhatgarh Dam	83
Longitudinal Section of Bhatgarh Dam	84
Head-works of the Nira Canal	88
Sections of Tank Dams in Rajputana	90
Grass Revetments in Tanjore	92

CHAPTER VI.

Delta of the Mahanuddee River	98
Weir across the Katjuri River at Naraj	101

CHAPTER VIII.

Kanasi Bandhara in Kandesh	114
Weirs on the Kurnool Canal in Madras	115
Head-works of the Betwa Canal	116
Regulator and Under-sluices of the Betwa Canal	118
Under-sluice Gates, Betwa Canal	120
Sections of Mandalay Weir and Under-sluices	121
Needle Girder of the Madaya Weir on the Mandalay Canal	122
Section of Head-sluice, Bari Doab Canal	126
Permanent Head-works, Eastern and Western Jumna Canals	127
Section of Under-sluices, Western Jumna Canal	128
Gate Grooves of Head-sluice, Western Jumna Canal	129
Cross Section of Jumna Weir	129
Head of Eastern and Western Jumna Canals	130
Section of the Escape Sluices at Faizabad, Eastern Jumna Canal	131
Section of Weir at Naushera, Eastern Jumna Canal	131
Gabions in the Khara Spur	132
The Earliest River Works of the Ganges Canal	132
River Works in the Ganges in 1898 at the Head of the Ganges Canal	133
Head of Ganges Canal	134
Ganges River Training Works, Spur Head, 1898	135
Cribs used in the Construction of Temporary Dams, Ganges Canal Head Head-works	136

CHAPTER IX.

Section of Ravi River at Site of the Sidhnai Weir	138
Sections of Sidhnai Weir on the Ravi River	139
Needle Weir across the Ravi River, Sidhnai Canal	140
Weirs on on the Rivers in Orissa	141
Site of Mahanuddee Weir in Orissa	142
Panchkoorah Weir, Midnapore Canal, in Bengal	143
Weirs on Deep Hard Sand	145
Weirs across the Coleroon in Tanjore	149
Section of the Sone Weir	150
Permanent Closure of the Centre Sluices of the Sone Weir	152
Crest Shutters of the Sone Weir	153
Section of the Under-sluices of the Sone Weir	153
Head-works of the Sirhind Canal	154
Weir and Under-sluices of the Sirhind Canal on the Sutlej	155
Crest Shutters on the Rupar Weir, Sirhind Canal	156
Pitching Blocks, Sirhind Canal	156

CHAPTER X.

PAGE

Sections of the Narora Weir on the Ganges, and of the Okla Weir on the Jumna River . . 157
River Training Works at the Head of the Lower Ganges Canal . . 158
Improved Type of Groyne Head, Lower Ganges Canal . . 160
Pressure Experiments at Narora Weir . . 161
Sections of Narora Weir, Lower Ganges Canal . . 163
Section of Weir, showing Path of Percolation . . 164
Under-sluice Shutters, Narora Weir . . 165
Head-sluice of Lower Ganges Canal at Narora . . 165
Head-works of the Chenab Canal . . 167
Sections of the Chenab Weir . . 168
Plan of One Bay of the Chenab Weir . . 169
Section of Under-sluices of the Chenab Weir . . 171
Cross Section of the Jhelum Weir . . 171
Elevation of Under-sluices of the Chenab Weir . . 172
Plan of Head-works, Jhelum Canal . . 172
Section of Under-sluices of the Jhelum Weir . . 174
Subsidiary Weir below the Delta Barrage, near Cairo . . 174
Original Section of the Delta Barrage . . 176
Delta Barrage as Reconstructed . . 176
Sections of the Zifta and Assiut Barrages . . 179

CHAPTER XI.

Under-sluices of the Bezwada Weir . . 181
Details of Shutters of the Bezwada Weir . . 181
Under-sluice Shutters used on the Orissa and Midnapore Canals . . 183
Under-sluice Shutters of the Sone Weir . . 185
Hydraulic Let-go Gear of the Under-sluice Shutters of the Sone Weir . . 189
Fouracres' Double Tumbler Shutter . . 191
Travelling Winch on the Chenab Weir . . 192, 193
Proposed Regulator Gates, Penner River, Madras . . 195
Whiting's Self-acting Waste Weir Gates . . 196
Automatic Waste Weir Gates of the Bhatgarh Dam, Lake Whiting . . 197
Automatic Gates on the Waste Weir of Lake Fife . . 199
One Group of Automatic Gates on the Waste Weir of Lake Fife . . 201

CHAPTER XII.

Head-sluice, Doomraon Branch Canal . . 202
Head-sluice on the Sarun Canals in Bengal . . 203
Head-sluice at Panchkoorah, Midnapore Canal . . 205
Shutters of Head Regulator, Sidhnai Canal . . 206
Shutters of the Bezwada Head-sluice, Kistna Canals . . 207
Traveller on the Head Regulator, Chenab Canal . . 208
Head Regulator of the Chenab Canal . . 209
Head-sluice of the Trebeni Canal . . 210
Chamkour Regulator and Escape, Sirhind Canal . . 211
Alipur Regulator on the Fuleli Canal in Sind . . 212
Needles and Horizontals on Egyptian Regulators . . 213
Escape, or Surplus Sluice, in Madras . . 215
Qushesha Escape in Middle Egypt . . 216
Sections of Canal Falls . . 217

CHAPTER XII. (*continued*).

PAGE
Cascade Fall on the Bari Doab Canal 218
Type of Canal Fall in Madras, Kistna Canal 219
Type of Canal Fall on Bengal Canals 220
General Plan of Lock and Fall on Bengal Canals 221
Bhawani Regulator with Lock and Fall, Sirhind Canal 222
Notch Fall on the Chenab Canal 223
Form of Notch used on Falls in the Punjab 224
Type of Girder Bridge on Bengal Canals 225
Over Bridge on the Buxar Canal, Bengal 226

CHAPTER XIII

Drains and Inlets on the Eden Canal in Bengal 229
Inlets on the Sirhind Canal in the Punjab 230
Inlet, Outlet, and Supply Sluices on the Orissa Coast Canal 231
Budki Super-passage on the Sirhind Canal 232
Kali Nadi Aqueduct on the Lower Ganges Canal 234, 235
Aqueduct on the Thora Nullah, Buxar Canal 238
Thapangaing Aqueduct, Mandalay Canal 240
Falling Side Shutters of the Thapangaing Aqueduct 241
Syphon carrying the Kao Nullah under the Sone Canal 242
Burra Bubsa Syphon on the Trebeni Canal 243
Section of the Barrels of the Ravi Syphon 245
Details of Ties in the Barrels of the Ravi Syphon 246
Super-passage on the Nira Canal in Bombay 248
Typical Section of Syphons on the Chenab Canal in the Punjab 249

CHAPTER XIV.

Navigable Canals and Steamer Routes in Bengal 255
Situation of Lock and Fall on the Ganges Canal 256
Diagram of Settlement of Foundations 257
Lock Walls on Bengal Canals 258
Tidal Lock on the Orissa Coast Canal 260
Lock Gates on the Midnapore Canal 262
"Ek-dum" Valve on Orissa Lock Gates 263
Lock Gate Valve on the Sone Canals 264
Double Lock on the Sone Canals in Bengal 265
Lock Gate Opening Gear in Bengal 266
Tunnel Valve on the Chitpore Lock in Calcutta 267
Iron Gates of the Chitpore Lock 269

CHAPTER XV.

Diagram Illustrating *Tatils* 285

CHAPTER XVI.

Contour Plan, Sidhnai Canal 287
Typical Sections of Indian Canals 290
Masonry Side Walls of the Kurnool Canal in Madras 291
Pipe Outlets for Village Channels in the United Provinces 296
Pipe Outlets for Village Channels in Bengal 298

LIST OF BOOKS AND PUBLICATIONS ON IRRIGATION.

TITLE.	AUTHOR	PUBLISHER OR PLACE OF PUBLICATION.	DATE.
Indian Storage Reservoirs with Earthen Dams.	W. L. Strange	Messrs. E. & F. N. Spon, London.	1904
Report of the Indian Irrigation Commission.	Colin C. Scott-Moncrieff.	Government Press, Calcutta.	1903
Irrigation in the United States	F. H. Newell	Crowell & Co., New York	1902 (?)
Reservoirs for Irrigation	James D. Schuyler	Chapman & Hall, London	1902
The Delta Barrage of Lower Egypt	R. Hanbury Brown	Cairo	1902
The Engineering Works of the Kistna Delta.	George T. Walch	Madras	1899
Manual of Irrigation Engineering	H. M. Wilson	Chapman & Hall, London	1897
Engineering Results of Irrigation Survey	H. M. Wilson	New York	1894
Irrigated India	Hon. A. Deakin	Messrs. Thacker & Co., London.	1893
Irrigation Canals and other Irrigation Works.	P. J. Flynn	San Francisco, California	1892
Irrigation in India	H. M. Wilson	Govt. Printing Office, Washington.	1892
Le Irrigazione nell' Egitto con tre carte annesse.	—	Rome	1892
The Nira Canal. A selection from Proceedings of the Government of Bombay.	—	Bombay	1891
Irrigation Manual	Lt.-Gen. J. Mullins, R.E.	Messrs. E. & F. N. Spon, London.	1890
Les Irrigations	A. Ronna	Fermin-Didot et Cie., Paris.	1888—89—90
Egyptian Irrigation	W. Willcocks	Messrs. E. & F. N. Spon, London.	1889 and 1899
Irrigation in California. The Field, Water-supply, and Works.	W. Ham Hall	State Office, California	1888
Agricultural Engineering in India	J. R. C. Nicholls	Office of "Engineering," London.	1888
L'Irrigation en Égypt	J. Barois	Imprimerie Nationale, Paris.	1887
Irrigation Development: France, Italy, and Spain.	W. Ham Hall	State Office, Sacramento	1886
Hydraulic Works	L. D'A. Jackson	Messrs. W. Thacker & Co., London.	1885
Irrigation in Western America	Hon. A. Deakin	Govt. Press, Melbourne	1885
Godavery, Kistna, Cauvery Delta, and Penner Anicut System. A selection from Proceedings of the Government of Madras.	—	Govt. Press, Madras	1883
Irrigation Works in Southern France	Claude Vincent	Govt. Press, Madras	1882
Continental Irrigation	H. L. Roth	Messrs. Trübner & Co., London.	1882
Report of the Indian Famine Commission, Part I. (C. 2591); Part II. (C. 2735); Part III. (C. 3086).	—	Parliamentary Paper, London.	1880 and 1885
Appendices of the above, Nos. I. to V. (C. 3086).	—	Parliamentary Paper, London.	1881

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Roorkee Hydraulic Experiments	Capt. A. Cunningham, R.E.	Thomason College Press, Roorkee.	1880—81
The Irrigation Works of India and their Financial Results.	R. B. Buckley.	Messrs. W. H. Allen & Co., London.	1880
Irrigation in India in Connection with Indian Deficits.	—	Messrs. Wyman & Co., Calcutta.	1877
Les Irrigations dans le Département des Bouches-du-Rhône.	J. A. Barral	Imprimerie Nationale, Paris.	1877
Les Irrigations dans le Département Vaucluse.	J. A. Barral	Imprimerie Nationale, Paris.	1876
Irrigation Works in India, Lectures on the	Col. F. H. Rundall, R.E.	School of Military Engineering, Chatham.	1876
Sardah Canal Project, Report on the	Capt. J. G. Forbes, R.E.	Oudh Government Press, Lucknow.	1871
Irrigation in Southern Europe	Lieut. C. C. Scott-Moncrieff, R.E.	Messrs. E. & F. N. Spon, London.	1868
Reservoirs in the Deccan Rivers	G. R. Carroll	Education Society's Press, Bombay.	1867
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Ganges Canal. Controversy between Sir Proby Cautley and Sir Arthur Cotton.	—	Printed for Private Circulation, London.	1863—65
Report on the Ganges Canal	Capt. J. Crofton	P. W. Dept., Calcutta	1865
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Ganges Canal Works, Report on the	Col. Sir Proby Cautley, K.C.B., F.R.S.	Messrs. Smith, Elder & Co , London.	1860
The Cauvery, Kistna, and Godavery. A Report on the Irrigation Works on those Rivers.	Capt. R. Baird Smith, R.E., F.G.S.	Messrs. Smith, Elder & Co., London.	1856
Professional Papers of Madras Engineers	—	Madras	1856
Canal Irrigation of Rohilcund, Report on the.	Capt. W. Jones, R.E.	Thomason College Press, Roorkee.	1855
Italian Irrigation	Capt. R. Baird Smith, R.E , F.G.S.	Messrs Blackwood & Sons, Edinburgh.	1852—53
Western Jumna Canals, Memo. on the	Major W. E. Baker, R.E.	Messrs. Smith, Elder & Co , London.	1849
Central Doab Canal, Report on the .	Major T. Proby Cautley, R.A.	—	1840

Roorkee Professional Papers.

These volumes contain many papers describing Indian Irrigation Works, and treating of their design, the duty and distribution of water, &c.

Selections from the Proceedings of the Government of India, in the Public Works Department.

The following "Selections," which refer to *Irrigation Works*, can be obtained from the Superintendent of Government Printing, Calcutta. They contain plates:—No. CCXV., Periyar Irrigation Project, Madras; No. CCIV., Orissa Coast Canal, Bengal; No. CCXVII., Buckingham Canal, Madras; No. CCXVIII., Rushikulya Project, Madras; No. CCXIX., Palar Anicut System, Madras; No. CCXXXI., Zhara Karez Irrigation Scheme, Baluchistan; No. CCXXXII., Betwa Canal Project, North-West Provinces; No. CCXL., Failure of the Kali Nadi Aqueduct, Lower Ganges Canal; No. CCXLVIII., Sidhnai Canal Project, Punjab.

THE IRRIGATION WORKS OF INDIA.

CHAPTER I.

GENERAL AND DESCRIPTIVE.

Necessity for Irrigation in the Tropics—Inequalities of Rainfall—Area Irrigated in India—Mechanical Methods of Irrigation—Well Irrigation—Geological Considerations—Tanks and Reservoirs in different Provinces—Karezes in Baluchistan—Inundation Canals—The Indus—Perennial Canals—Progress of Irrigation Works in India—Utilisation of Water Supply—Storage Works—Canal Extension in the Punjab.

CULTIVATION in the tropics can be, and is, in many cases, effected by the aid of the natural rainfall only; but there are many parts in which artificial watering of some portion, at any rate, of the crops is essential. The rainfall, in some parts, may be utterly insufficient in every season to mature the crops: this is the case, for instance, in Sind and in parts of the Punjab, in India, where the rainfall of the year averages from 2 to 4 inches only, and in the whole basin of the Nile in Africa, where the rainfall, on large tracts, is practically nothing at all. Or the rainfall may be amply sufficient in total quantity, but badly distributed with reference to the seasons or to the requirements of the crops: this is the case in Southern India and in the Madras Province particularly, where the rain, though the total amount ranges from 40 to 60 inches in the year, generally falls in short periods; it is not uncommon to have bursts of 12 inches in twenty-four hours. Even in parts of the Himalayas, where the yearly rainfall varies from 50 to as many as 100 inches, crops grown on the terraces in the mountains are matured in the dry season by artificial irrigation. Hence, from the earliest ages, man has devised many systems for carrying the water to the land he cultivated. In those tracts where the total rainfall is inadequate, irrigation was effected either from wells or by leading the water from streams; and, in other districts, where the rainfall was copious but unsuitably distributed, by the storage of the surplus water of one period in surface tanks and reservoirs, until, at another period, it was distributed on the fields. The Map of the Irrigation works and Rainfall of India, facing page 6, shows the general distribution of the rainfall on the continent.

By far the greater part of the rainfall of India[1] is due to the south-west monsoon, which occurs between June and October. Indeed, it may be said that in the Bombay Presidency the fall is restricted to that season. The latter part of the cold weather and the earlier spring months are the times of the winter rainfall in Northern India. The extreme north-western districts receive, at that time, about half their annual fall. During the hot weather months, that

[1] Report of Indian Irrigation Commission, 1901—1903.

is, from March to May or June, thunder-storms are not uncommon in parts, but, generally, the greater portion of India is without rainfall at that time. The intensity of the rainfall varies very greatly. The clouds, drifting eastwards from the Indian Ocean, impinge on the western ghâts, where the greatest fall occurs; after passing the summits of these hills the clouds have lost their density, and the incidence of the annual rainfall decreases, almost suddenly, from 100 to 25 inches. A long tract of land is left, extending from Rajputana to Cape Cormorin, in which the rainfall is scanty and precarious. The average fall of the whole of India is about 42 inches; and, taking the country as a whole, the amount does not vary greatly from year to year. But, in particular tracts, which are in themselves large areas, the rainfall is subject to very great variations. Speaking generally, it may be said that the smaller the average rainfall of any tract is, the greater is the probability that the gross fall in it, in any particular year, will be below the average of a long series of years. When the average rainfall only amounts to 10 or 12 inches, cultivation is almost impossible without irrigation. There are 150,000 to 200,000 square miles of country in this condition. On the other hand, where the rainfall exceeds 70 inches, as it does in eastern Bengal and Assam, there is hardly ever any necessity for irrigation at all. Intermediate between these two conditions there is a tract of about a million square miles, where irrigation alone can secure the country from an occasional loss of crops, although such a loss will never occur simultaneously over all the area.

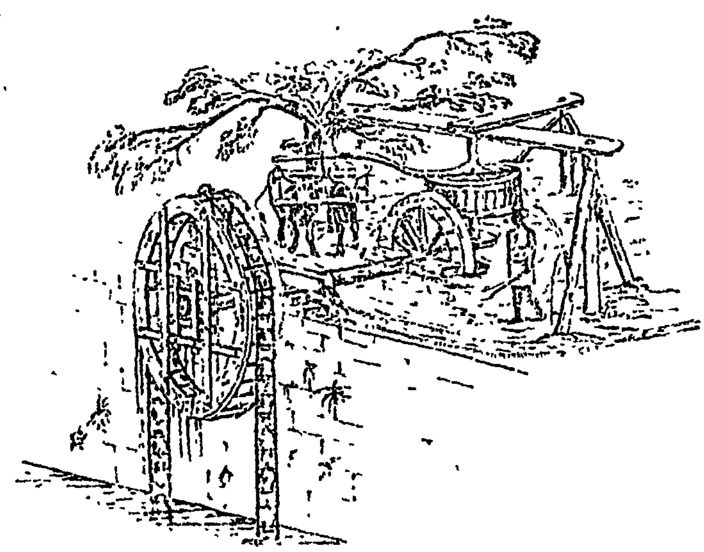
It is not an uncommon error to suppose that all crops in India are irrigated artificially in some way. The truth is that less than 20 per cent. of the crops which are sown are irrigated in any way except by the rainfall. The Irrigation Commission of 1901-1903, writing of British India (*i.e.*, excluding the native States), gave the following[1] figures :—

Provinces	Area in Square Miles	Population in Millions.	Average Area in Millions of Acres Annually Sown.	Area ordinarily Irrigated in Millions of Acres.	Percentage of the Area Sown which is Irrigated.
Upper Burmah	87,000	3·84	4·66	0·82	17·7
Bengal	151,000	73·04	63·66	6·35	10·0
United Provinces	107,000	47·69	41·09	11·06	26·9
Punjab	114,000	22·36	28·21	10·43	37·0
Madras	142,000	37·69	36·57	10·53	28·8
Sind	47,000	3·21	3·32	2·92	88·0
Bombay	76,000	14·53	24·33	1·08	4·4
Five smaller Provinces[2] ..	132,000	13·60	24·22	0·90	3·7
Total British India ..	856,000	215·96	226·06	44·09	19·5
And the Commission added the following figures with reference to the more important native States :—					
Native States	438,000	51·32	71·07	7·76	10·9

It was estimated that of the 44 million acres which are irrigated in British India, 13 millions are irrigated from wells, 17 millions from canals, 8 millions from tanks, and 6 millions in various other ways. The Irrigation Commission stated that rather more than 18½ million

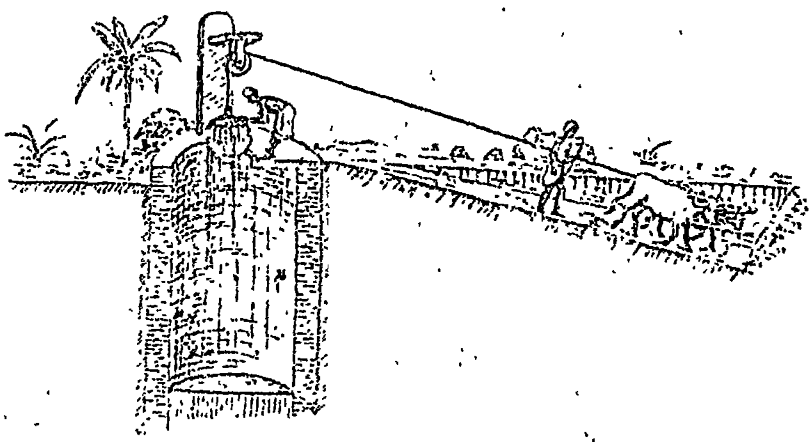
[1] Page 10, para. 44, of Report of Irrigation Commission, 1901—1903.
[2] Ajmer—Merwara, Baluchistan, Central Provinces, Berar, Coorg.

acres were irrigated from works administered by the Government, and the remainder, or $25\frac{1}{2}$ millions, from wells and private irrigation works.



THE PERSIAN WHEEL.

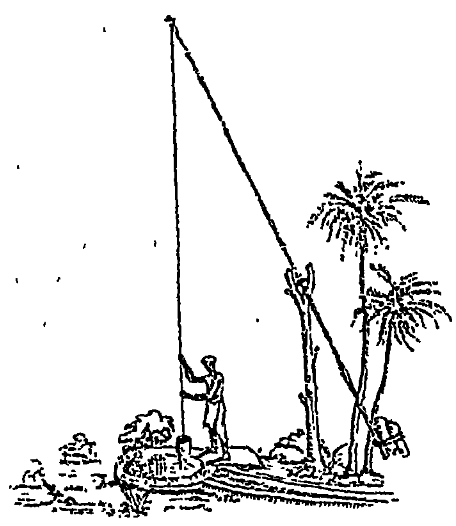
The old mechanical means employed for lifting water from wells, from streams, and from low-lying depressions, are of various kinds; all of them, with slight modifications, are to be found both in Africa and in Asia. The Persian wheel, which is found in various forms in Egypt, in Sind, and the Punjab, consists of a series of earthenware pots revolving on a wheel with a horizontol axis; each pot delivers its contents into a trough, and it then descends to the water to be filled again. In some cases the earthen jars are attached to endless ropes which revolve on the wheel, and sometimes they are attached to the circumference of the revolving wheel itself. These wheels are generally actuated by bullocks, and sometimes by camels or horses; and, in Egypt, one sometimes sees a camel and a donkey both harnessed together in the same track. In some places, more particularly in the Fayoum in Egypt, where there are many small canals with comparatively rapid slopes and high velocities, these wheels — or *sakias*, as they are called—are driven, usually as undershot wheels, by the stream itself. In the Punjab it is not an uncommon thing to see oxen lifting water by Persian wheels from depths of 50 and 60 feet for the irrigation of spring or summer crops.



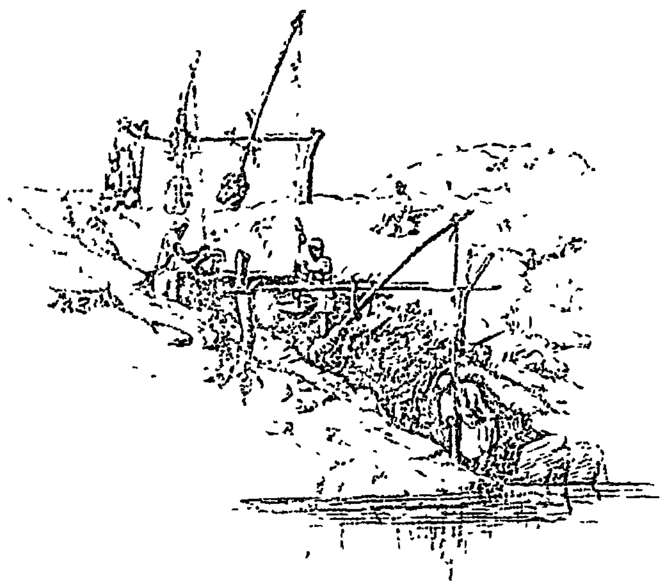
THE MOTE.

Another system which is extensively used in India for the larger lifts is the *mote*. Two bullocks raise a leathern bag by means of a rope working over a pulley; sometimes a cord is attached to the lower end of the leathern bag, and by an ingenious but rough contrivance, the driver, by manipulating the lower cord, lets the water escape from the lower end of the bag, when the bag is at the top of the lift. But usually the *mote* is worked by two men, the driver, and another at the well head; the man at the well pulls the leathern bucket over the trough or channel in which the water runs.

For smaller lifts of 4 to 10 feet the appliance shown in the adjoining sketch is often used. This arrangement is called a *lât* in Upper India; a *picottah* in the south, and, in Egypt, under the name of the *shadouf*, it is extensively employed on the banks of the Nile.



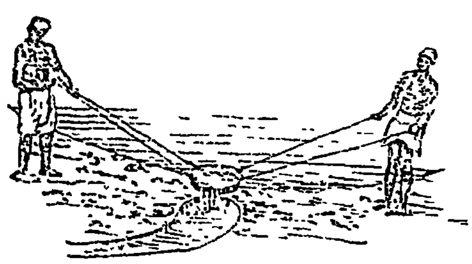
THE LAT OR PICOTTAH.



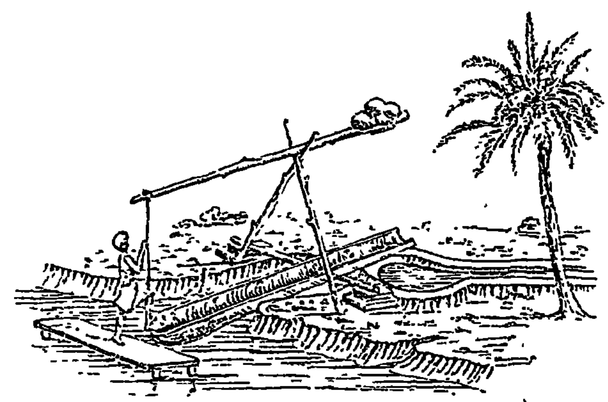
THE SHADOUF.

It consists essentially of a bucket, which may be of leather, earthenware, or iron, hung to a pole which can oscillate in a vertical plane; the short end of the pole is counterbalanced by a weight, usually a clod of earth or an old grindstone, so that the bucket, when full, requires but little force to raise it. The man working this contrivance stands at the edge of the well and uses his weight to depress the bucket into the water, when, with but little force, it rises to the point where the water is delivered. Archimedean screws are used in Lower Egypt for lifts not exceeding about 3 feet, and are said to give a much larger duty, for small lifts, than any of the other arrangements.

The basket scoop is used for smaller lifts of from 1 to 4 feet, and the *doon* is common in Bengal for lifts of about 2 or 3 feet. The *doon* is an oscillating trough, usually half the stem of a hollowed tâl tree, which oscillates on a fixed centre, so that one end is alternately depressed into the water and raised above the level of delivery; the weight of the water is



THE BASKET.



THE DOON.

equalised by a counterbalance, so that the man, who stands over the water on a plank, can depress the end of the *doon* into the stream with his feet, and then, by stepping on to the plank and lifting slightly with his hands, can slope the trough towards the point of delivery, and thus enable the water to run out into the channel. Experiments made by Mr. Allan Wilson in Central India on these methods of raising water gave the following results :—

	Number of cubic feet of water raised one foot high in ten hours.
Bullock *mote* with two bullocks, one man	79,200
Picottah or *lât* with two men...	57,600
" " one man	33,000
Basket scoop with two men	20,178

The results are reduced to the standard of ten hours and a foot high for convenience of comparison. Inquiries made in Shahabad, in Bengal,[1] as to the average cost of irrigation by these different methods, gave the following results, the depth of the water in wells being about 15 feet:—

		Rs.	a.	p.
Cost of irrigating one acre with the *mote*, per crop	... ...	9	0	0
,, ,, *lât* ,,	... ...	13	0	0
,, ,, basket ,,	... ...	6	8	6
,, ,, *doon* ,,	... ...	3	14	0

The irrigation with the basket and *doon* would have been from lifts of from 1 to 4 feet only. The figures given took account of the value and life of the material used, and of the cost of a man's labour. All these methods of raising water are more expensive than artificial irrigation, which, in India, costs on the average about Rs. 3·5 an acre—the lowest provincial rate being Rs. 1·9 in Sind and Bengal, and the highest Rs. 4·8 in the Bombay Deccan. In some cases, however, irrigation from wells really costs the actual cultivator little or nothing, as he only employs himself and his bullocks at times when there is no other work on hand.

Irrigation from wells is largely practised in India. It is estimated that no less than 13 million acres in British India are watered by wells which have been entirely constructed by private persons, and not by the State. Cultivation effected from wells is generally of the more valuable kinds of crop, and it is estimated that the value of the out-turn from well irrigation is from one-third to one-half of that of the whole of the irrigated crops in India. Of the 13 million acres irrigated in British India by wells, the greater proportion—considerably more than one-half—is in the Punjab and United Provinces. The average cost of a permanent well is from 300 to 600 rupees, according to size and depth. The average area irrigated by a well in the Punjab, where they are mostly permanent, is 12 acres. In the United Provinces, where the wells are largely of a temporary character, the average area per well is not more than 4 acres; in Southern India the average area is between 2 and 3 acres. Well irrigation extends but slowly, and it must necessarily be so, as, not only is the first cost of permanent well a heavy charge on the land it irrigates, but its working requires capital and high cultivation. The State encourages the construction of wells in India—first, by agricultural advances specially given for the purpose; and, secondly, in some cases, by the temporary exemption of the lands concerned from any enhancement of land revenue in consequence of the improvements. The Irrigation Commission of 1901—1903 reported that in the United Provinces, the Punjab, Bombay, and Madras, where well irrigation is most extensively practised, the increase in the number of permanent wells in ten years have been 11, 25, 33, and 44 per cent. respectively.

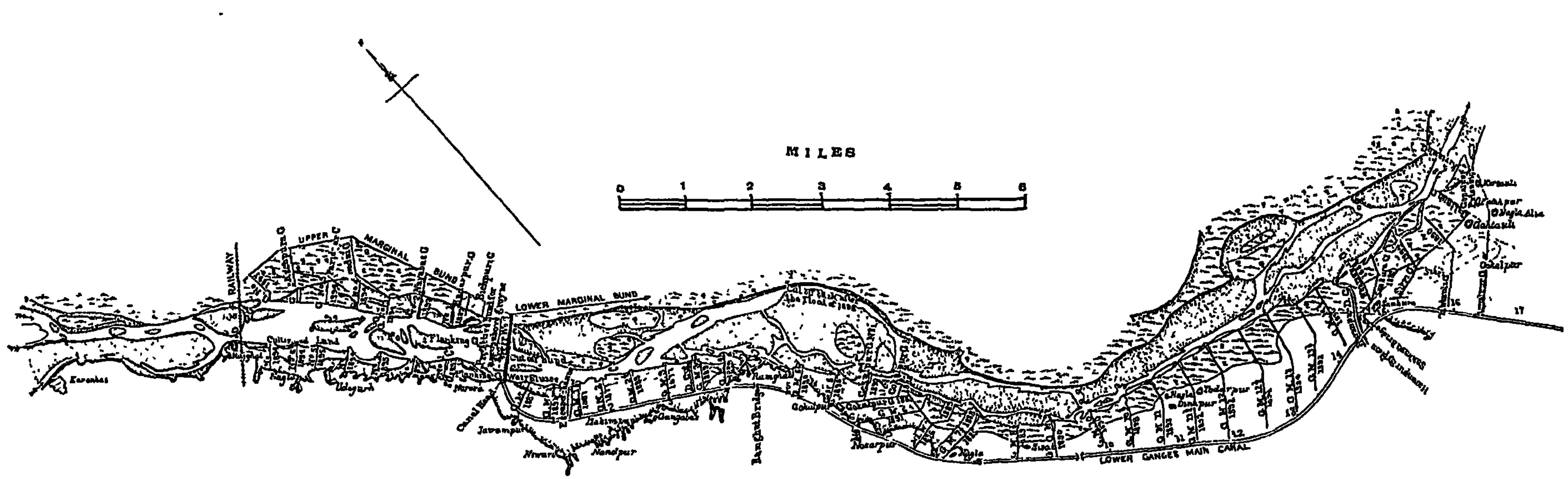
It was reported by Colonel Baird Smith that, in 1860, there were 70,000 masonry wells and 280,000 temporary earthen ones in the tract lying between the Jumna and the Ganges, from which 1,470,000 acres of crops were irrigated by lift, and, although this tract is now commanded by the Ganges Canal, many of these wells are still used to irrigate lands which are not watered by the canals.

The cultivated soils[2] in India are, with one exception, generally suitable for irrigation. The principal geological divisions are the Alluvial, the Deccan trap, and the Crystalline and Sandstone formations.

The Alluvial formation covers the greater part of Northern India. It reaches from the

[1] Report on the Sone Canals, by Mr. H. C. Levinge, late Chief Engineer of Bengal.

[2] Report of the Indian Irrigation Commission, 1901—1903.



RIVER TRAINING WORKS AT THE HEAD OF THE LOWER GANGES CANAL.

reached. The danger which was feared was that the river might cut into the low lands on the left bank, and possibly outflank the weir on that side; it was also necessary to protect the low land on that bank from inundation. The river, when the head-works were commenced, had a course which was not nearly as straight on the weir as it now is: it ran in a tortuous channel much nearer to the marginal embankment. One of the main objects of the training works was to force the main stream away from the left bank and to compel it to flow in a direct channel from the railway bridge to the weir. Since the works were commenced there has been a constant struggle with the river, which is still kept up, to force it to flow along the right bank.[1] The weir, including the scouring sluices, is 4,200 feet long, and the crest is 10 feet above the normal low water level of the river: it obstructs about half the waterway of the river, and the afflux caused by it is about 2 feet.

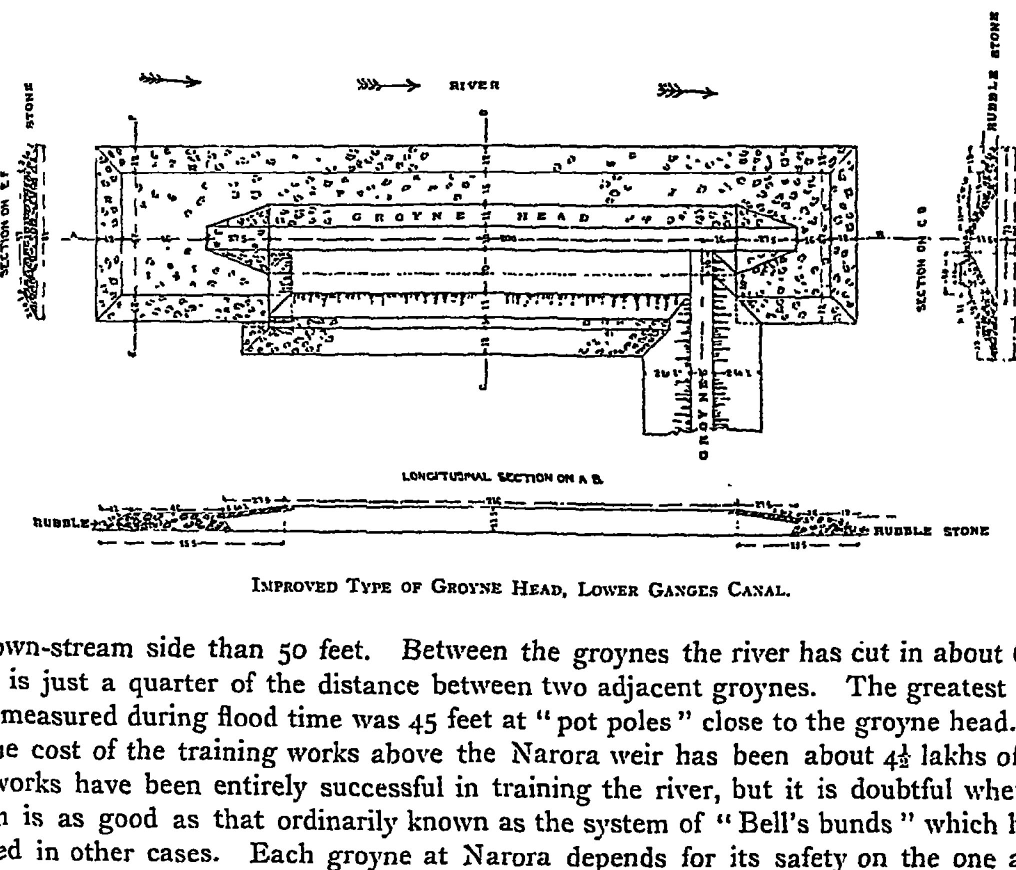
The Ganges river is trained,[2] above the weir, for a distance of 5½ miles on both banks, and for a distance of 16 miles below the weir on its right bank. Owing to the raising of the flood level and the existence of an old channel of the river on its left bank in the *khadir*, or low-lying land, on the margin of the river, it was necessary to construct a marginal embankment, at a distance of about 1 mile to ½ mile from the edge, in order to prevent high floods from spilling into the old channel and outflanking the weir. The railway embankment which crosses the river valley about 5½ miles above the weir was a convenient *point d'appui* from which to start this embankment. The distance between the high bank of the river on the right and the marginal bund on the left is about 1½ miles, through which breadth, before the construction of the present training works, the river oscillated from side to side, threatening destruction to the marginal bund. Moreover, as the valley was much too wide and the velocity of the current was checked by the weir, large islands were formed by silt deposits which masked half the length of the weir. The canal takes out of the right bank at a point where the level of the country is 50 feet above high flood level. To avoid the deep excavation, which would have been very costly, the canal was aligned along the *khadir*, or low land, for the first 16 miles. At the time of its construction it was about ½ mile from the edge of the river channel as it existed at that time.

Below the weir, the river was drawn towards the right bank by the action of the undersluices of the weir, which are worked almost continuously in the flood season to keep the channel to the canal head open. These sluices are capable of discharging 40,000 cubic feet a second, and, as the ordinary flood discharge of the river is not more than 120,000 cubic feet, the continuous discharge of this large volume induced the river to set on to its right bank, and the erosion of the land between the river and canal set in from the date the canal was opened in 1877. In 1887, ten years later, only about 2 furlongs of low-lying land remained between the river and the canal at various points in the first 12 miles below the weir. The canal at that time was in a highly precarious position. Various expedients were adopted to protect it at the threatened points. These were at first of a temporary nature. Both tree-spurs and earthen bunds across the spill channel, with others projecting into the river, were used, but they were all usually washed away by the first floods.

These temporary expedients were succeeded by groynes with horse-shoe shaped heads of kunker in cribs or crates. These, too, were a failure: five groynes of this type were washed away in twenty-four hours during the high floods of 1880. In 1887 groynes of an improved pattern, having heads of kunker in the form of a cross with a long sloping nose, were introduced, and twenty-eight of this pattern were constructed, which were fairly successful.

[1] "Roorkee Professional Papers," by Major H. H. Jones, R.E., vol. vi.
[2] Note by Mr. Hutton.

In 1893 it was decided to train the river above the weir as well as below it, and a new type of groyne was introduced, which is illustrated in the sketch below. In order to train the river directly on to the weir and obtain a channel free from islands, groynes on each side of the river were erected at ½-mile intervals, each pair of groynes facing each other. The distance across the river between the heads of the groynes was 3,000 feet, which is about the normal width of the river. This type of groyne has acted remarkably well, and there is now a clear straight channel between the railway bridge and the weir, a distance of 5½ miles. The groyne is extended well up-stream to protect the sand embankment from the inevitable swirl which takes place behind it, and sufficiently down-stream to afford protection from similar action on the down-stream side. The groyne head is 400 feet long, 300 feet being on the up-stream side of the centre line of the embankment and 100 feet on the down-stream end. Practical experience has demonstrated that, with such groynes at ½-mile intervals, the river has been unable to cut in closer to the bund, on the up-stream side, than 100 feet and on



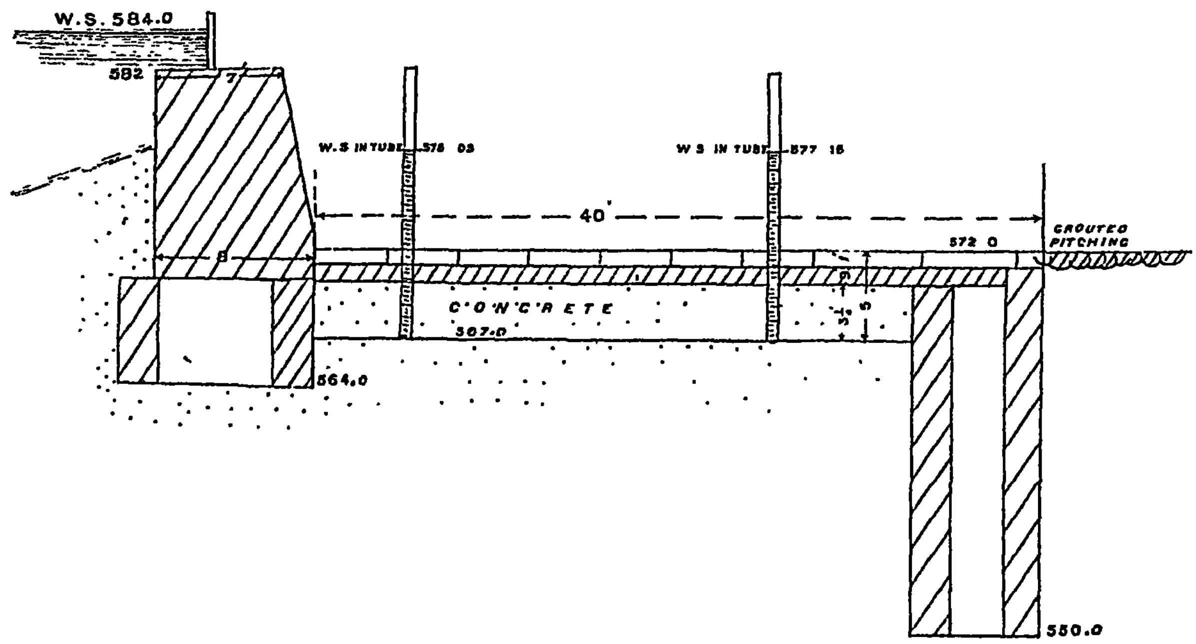
IMPROVED TYPE OF GROYNE HEAD, LOWER GANGES CANAL.

the down-stream side than 50 feet. Between the groynes the river has cut in about 660 feet, which is just a quarter of the distance between two adjacent groynes. The greatest depth of scour measured during flood time was 45 feet at "pot poles" close to the groyne head.

The cost of the training works above the Narora weir has been about 4½ lakhs of rupees. The works have been entirely successful in training the river, but it is doubtful whether the system is as good as that ordinarily known as the system of "Bell's bunds" which has been adopted in other cases. Each groyne at Narora depends for its safety on the one above it, and the failure of one might entail the destruction of all. The system does not prevent the formation of shoals and islands above the weir. These shoals have induced currents parallel to the axis of the weir, and, in order to prevent the scour which might undermine the up-stream apron, groynes at right angles to the axis of the weir were constructed in 1899. These were in addition to the groyne which had been previously constructed between the weir proper and the under-sluices.

The Narora weir, as originally constructed, consists of a wall 8 feet thick at base and 10 feet high, founded on a line of blocks or wells 10 feet square and 18 inches thick, sunk 7 feet

below the river bed. Below the wall is a horizontal floor 40 feet wide and 5 feet thick, consisting of concrete 3 feet 3 inches thick, covered with a 9-inch course of brick masonry topped with 12 inches of ashlar. The wells at the toe of this floor are circular, 8 feet in diameter, and sunk from 20 to 30 feet in the sand. Below the floor is a talus 100 feet long, consisting of block kunkur pitching, the surface of the upper 40 feet being laid in concrete. The crest of the weir was originally built without the shutter which has now been erected continuously along it, as shown in the sketch, page 157. The crest was simply covered with ashlar 12 inches thick; these cover stones were thrown out of place in considerable lengths, the stones being lifted and thrown over the weir. The ashlar as it is now laid stands well, but it is laid with much coarser joints than the original work. It is a mistake in hydraulic work to attempt to deal with too fine joints; the result is that they do not get fully filled with mortar, and the water forces its way through them: coarse joints which can be thoroughly filled stand much better. This is



Pressure Experiments at Narora Weir.

shown in several cases: the floor of the Sone under-sluices and the floors of the falls or weirs in the Sone Canals, which are covered with 15-inch ashlar, were, in the earlier years, frequently disturbed by the water working its way under the stones and lifting them bodily upwards: in several cases the floors of canal falls were found to be partially arched upwards when the canal was dried, and stones 5 feet by 2 feet by 15 inches were lifted bodily and removed 10 or 12 yards from their beds. This has now been cured by more careful bedding of the ashlar. The crests of the Ravi and Jumna weirs, which are laid in boulder masonry, stand well, although the individual stones are much lighter than those originally used in the Narora weir, and the upper Godavery weir, which consists of rubble masonry only, has stood perfectly well: it is smoothed off with cement.

In March, 1898, some 350 feet of the floor of this weir was "blown up" by the water pressure below it. Only a few days previously, in quite a different part of the weir, two pipes[1] were put down into the floor with the object of testing the pressure below it, as some doubts existed as to its stability. The sketch on this page shows the result.

[1] Note by Mr. J S. Beresford, C.I.E., dated Jan. 30th, 1901.

The head on the weir at the time was about 12 feet. It will be seen that, about 13 feet from the up-stream side of the core-wall, the pressure on the bottom of the floor was that due to a head of 11 feet of water, and that 30 feet from the same point the pressure was that due to a head of about 10 feet. That is to say, the 5-foot floor, when the river bed below the weir was dry, was hardly in a state of equilibrium. At the time of the accident[1] a strong spring burst through the floor at the toe of the crest wall, and, passing under the stone flooring, lifted it bodily over a length of 340 feet to a maximum height of 2·23 feet. The weir wall settled, in a length of 120 feet, about 3 inches, and the flooring showed vertical cracks. The grouted pitching below the floor was "blown up." Up-stream of the part of the weir which was damaged the apron had disappeared, and the wall was exposed to a depth of 8 or 9 feet. Borings through the floor revealed cavities below it extending to about 50 feet on each side of the point of fracture. The weir was strengthened by a broad impervious floor above the breast-wall of the weir (see Plate on opposite page). The floor was about 80 feet broad, with a line of sal sheet piling along the up-stream face; the floor consisted, first, of 2½ feet of puddle of good brick clay, worked up at site in 6-inch layers; over this a layer of river sand 12 inches thick was laid to prevent any subsidence of the pitching, which was laid above it. This pitching was 2 feet thick, and divided into compartments by walls of block kunkur laid in lime. The up-stream face of the whole apron was protected by a wall of kunkur masonry 5 feet thick, carried 6 inches below the bed of the puddle, and above this was a berm of kunkur pitching 15 feet wide. On the old floor of the weir a dwarf wall 3 feet high was built, 30 feet below the weir wall, thus forming a cushion of water below the weir wall, and below this dwarf wall a slab of concrete 25 feet wide and 1½ feet thick was laid. The up-stream face of the weir was protected by additional groynes about 550 feet long, thrown out at right angles to the weir, to prevent any parallel currents.

The accident to this weir, and the subsequent investigations made in repairing it, proved that the original weir was decidedly insecure, and that the main cause of its weakness lay in the insufficient provision made against percolation under the floor. The lesson to be learnt from it is that on such light sandy soils an ample and impervious up-stream apron is essential, and that parallel currents are particularly dangerous.

Both theoretical consideration and practical experiments[2] have proved that the volume of water percolating through sand—

(1) through a given length of sand traversed, varies directly as the head of pressure;

(2) with a given head of pressure, varies inversely as the length of sand traversed;

(3) with sands of different degrees of fineness, or with different degrees of consolidation, varies directly with the amount of interstitial space, the resistance to flow being wholly due to surface friction in the interstices of the sand;

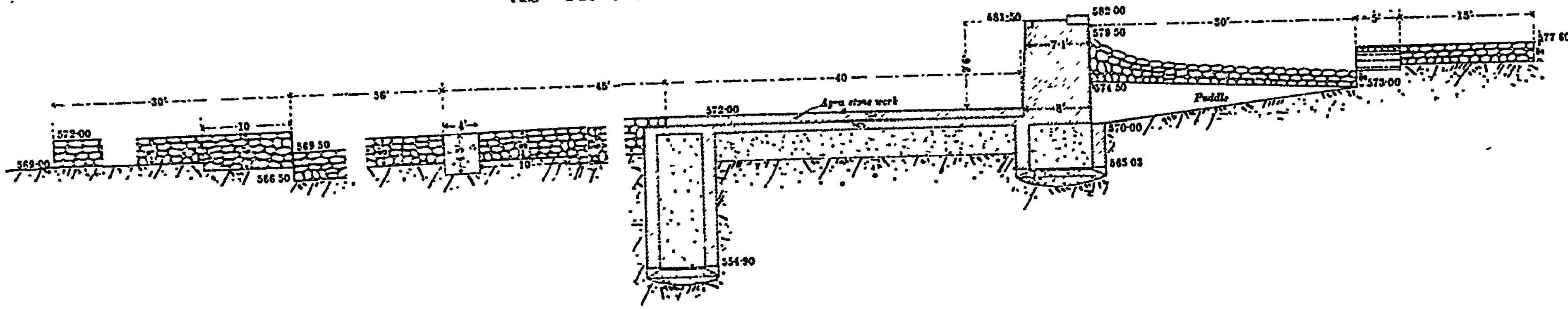
(4) other conditions being the same, the volume discharged varies directly with the sectional area of the sand.

Further, a consideration of these facts leads, obviously, to the conclusion that the pressure transmitted by water through sand, under certain heads, at different distances, is simply that due to the hydraulic gradient, on the length of the path of the water through the sand, up to the point where the pressure has to be determined. In the case, then, of a weir, such as that at Narora, an impervious floor, laid on the river bed above the weir wall, by increasing the length of the path of the water percolating beneath the structure, reduces the upward pressure on the

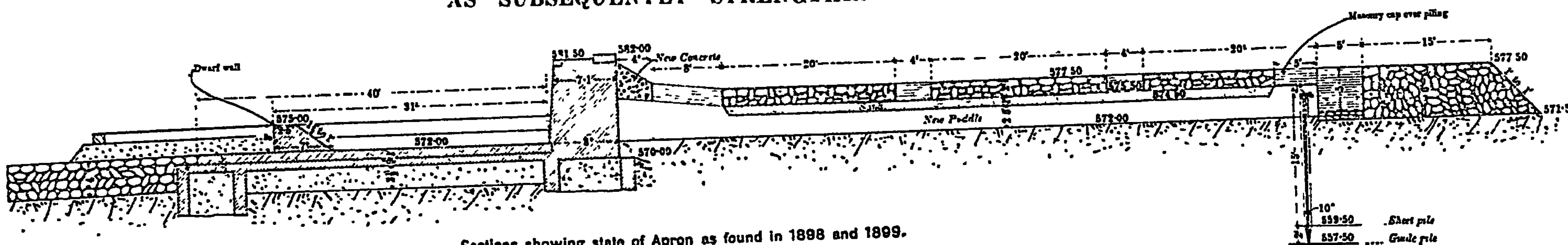
[1] Note by Mr. N. F. McLeod, Superintending Engineer.

[2] Technical Paper No 27, issued by the Government of India, 1902. "Experiments on the Passage of Water through Sand"

AS ORIGINALLY CONSTRUCTED



AS SUBSEQUENTLY STRENGTHENED



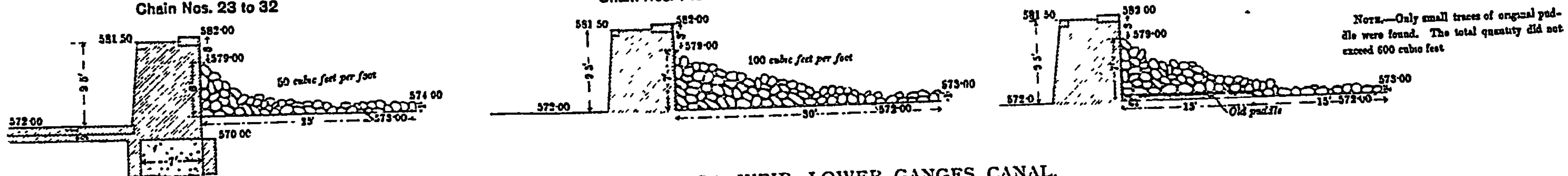
Sections showing state of Apron as found in 1898 and 1899.

Since the weir was built deep holes scoured along face have from time to time been filled in with block kankar, &c.

Chain Nos. 23 to 32

Chain Nos. 1 to 23 and 32 to 38.

Chain Nos. 6, 7, 9, and 10, showing old puddle.



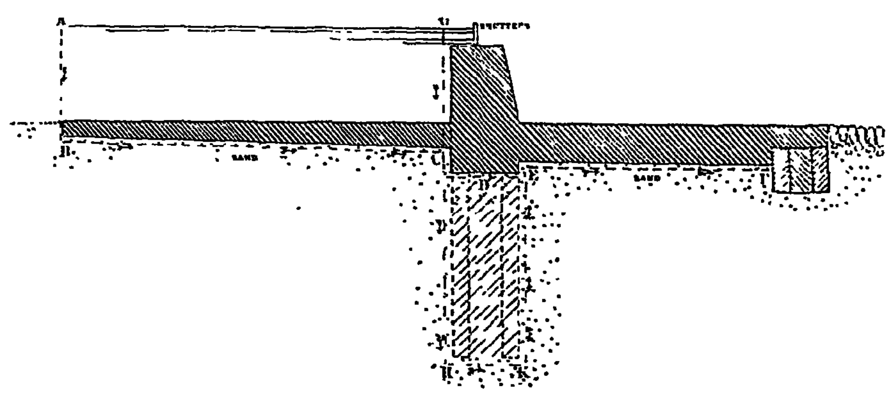
SECTION OF NARORA WEIR, LOWER GANGES CANAL.

floor below the core-wall. Thus the upward pressure on the floor E F is determined by the hydraulic gradient of the water passing through the sand on the path A B C D E F.

That upward pressure would be the same if the upper floor B C were omitted and the curtain-wall C H K E constructed instead, if the path of the water G C H K E in that case were the same length as A B C D E. The floor is cheaper to construct, more easily made impervious, and does not disturb the foundation of the weir as the curtain-wall does.

The shutters on the crest of the Lower Ganges weir are similar to those on the Jumna weir of the Agra Canal (page 166), they fold down on to the weir crest in floods. They are rarely lifted or lowered more than once in the season, and no difficulty is found in manipulating them.

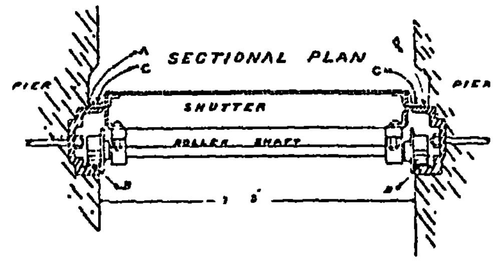
The under-sluices consist of forty-two openings of 7 feet 3 inches each. These small openings are found to be sufficient to maintain a good channel in front of the head-sluice of the canal. The design of the under-sluices is peculiar. It consists of two tiers of arches between the piers. The lower tier of arches rises a little below high flood level, so that the floor above the arches is under water 4 or 5 feet in a high flood. The upper tier of arches makes a covered subway through which there is a passage from end to end of the under-sluices formed by arches in the upper portions of the piers. This subway is very convenient to the men who have to manipulate the gates, and it is also useful for the repair of the shutters, as each one can be drawn up and deposited in the subway. The roadway above the upper tier of arches is 10 feet above the highest flood, and on this roadway a travelling crane runs, by which the shutters of the under-sluice are manipulated. The work is divided into three groups of shutters by piers 7 feet 3 inches thick, but the intermediate piers are only 2 feet 9 inches thick. The part of the foundation which lies under the piers and superstructure is entirely composed of masonry blocks 18 inches thick, which are sunk below the floor. The front row of blocks are each 11 feet long by 6 feet broad, sunk 15 feet, and the three lower rows are 10 feet square sunk 10 feet; all the blocks are filled with concrete. The floor, which is 427 feet by 155 feet, is entirely surrounded by wells sunk to various depths, and also divided into three bays by wells sunk in the line of the thick piers. The floor is 5 feet thick, similar to the weir flooring. Below the floor is 100 feet of kunkur block pitching. Underlying the light sand of the river bed is a stratum of clay connected with the high bank on the right of the under-sluices; most of the blocks and wells in the under-sluice floor are sunk to the clay, and these blocks and wells in the weir proper, which are within 500 feet of the under-sluices, are sunk into the clay, with the object of securing the weir against the scour of the water issuing from the under-sluices. Altogether the structure of the under-sluices is an exceedingly strong one.



SECTION OF WEIR, SHOWING PATH OF PERCOLATION.

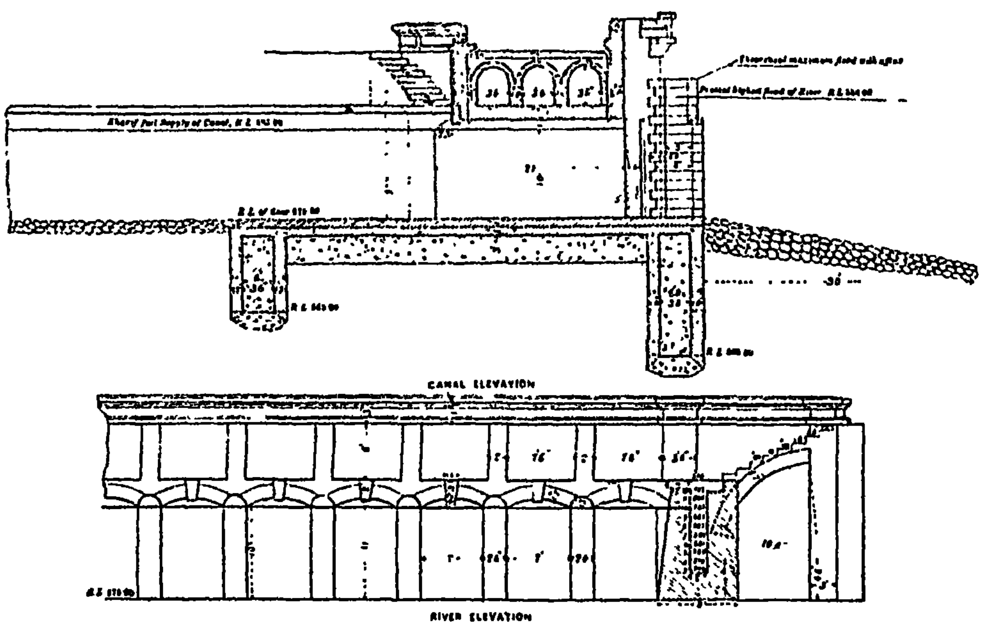
The level of the under-sluice floor is 572·00, which is the same as the weir floor; the level of the weir crest is 582·00, and the top of the weir crest shutters is 585·00. The under-sluice shutters are 13 feet high, the top of the gates being 585·00. They are iron draw-gates, lifted

vertically in grooves by a travelling winch on the upper roadway, which is at 600·00, the highest flood level above the weir being 590·00. The under-sluice gates can be lifted until the top of the gate is at the upper platform level (600·00) so that the lower edge of the gate is at 587·00, or 3 feet below the highest flood. The masonry platform over the lower arches is also below high flood level. It might be thought that it would have been better to have arranged so that the gates and lower arches would have been clear of the high flood, to avoid floating trees and brushwood, as has been done in the case of the Ravi, Sutlej, and other weirs, but no practical difficulty has ensued, as there appears to be but little floating *débris* in the river at this point.



UNDER-SLUICE SHUTTERS, NARORA WEIR.

The under-sluice gates, which are of wrought iron, are unlike those in any other weir. Each gate is fitted with four pairs of rollers, which are keyed to a wrought-iron shaft which is continuous across the gate. These rollers run in vertical cast-iron grooves, bolted to the piers, as shown by the cross section in the sketch. The paths B, on which the rollers run, are vertical; the flange A of the grooves is tapered slightly, and the angle-iron C which is riveted to the gate is set at a corresponding angle; when the gate falls vertically on the floor, guided by the rollers, the angle-iron C bears on the tapered face A, and staunches against it, the pressure being thus removed from the rollers to a great extent. As soon as the gate is lifted an inch or two from the floor, the rollers come into bearing and the friction on the face A ceases. The arrangement is a good one but expensive, and perhaps more elaborate than the occasion demands.



HEAD-SLUICE OF LOWER GANGES CANAL AT NARORA.

The section of the head-sluice is shown in the sketch.

The floor, it will be noticed, is at 575·00, or 3 feet above the under-sluice floor. The work is surrounded with blocks or wells sunk into the sand, and the floor is divided by lines of blocks the same as the under-sluice floor. The foundation consists of concrete rammed into the compartments formed by the sunken blocks. The high level of the head-sluice floor, as compared with that of the under-sluices, is of advantage in excluding sand from the canal bed. The silt in the waters of the river is very fine sand mixed with a considerable proportion of earthy matter, which is advantageous to the crops. The maximum velocity in the canal is rarely above $2\frac{1}{2}$ feet a second, which is sufficient to carry forward a large proportion of the silt to the fields. A certain amount of silt is deposited in the first two miles of the canal, but it is not much, and no dredging at all is necessary. At the

second mile of the canal there is a powerful escape (with 70 lineal feet of waterway down to the canal bed) by which the discharge of the canal can be returned to the river; the scour induced in the canal by this escape can be used to displace the greater portion of the silt deposited in the flood season. There is an ample supply of water in the river, the minimum discharge being about 3,000 cubic feet a second.

The Okla weir is believed to have the greatest width in cross section of any weir in India. In parts it is as much as 250 feet from the toe of the upper pitching to that of the lower talus. There are, first, two longitudinal walls 30 feet apart from centre to centre[1] and 4 feet thick; the upper one is 10 feet and the lower one 9 feet high; the interval between them is filled with rubble stone and carefully packed with very large rubble on the top. There is a third wall 4 feet 9 inches high 40 feet below the second one, and the interval is packed in the same way. The rubble used in the packing is very large; there are occasional stones as much as 6 feet by 3 feet by 2½ feet, and all the stones are larger than those usually employed in such work. The weir was much damaged by the first floods which passed over it before it was completed in 1871, and large quantities of rubble had to be thrown in below the talus of the weir, and below the head-sluices, which were very nearly carried away, a hole some 50 feet deep being scoured out at the end of the floor. The velocity over the crest of the weir in this flood was 9·3 feet a second, but that over the talus where the damage was done was estimated to be over 18 feet a second at a point some 40 feet below the crest. The weir was at first constructed without any shutters on the crest, but it was found necessary to raise the level of the pool, and wooden shutters 3 feet high were erected as shown in the sketch on page 157. These are hinged by holding-down bolts to the weir at their lower edge, and, when erected, are held up by chains in front of them, which are fitted with let-go gear. The floods in the river rise slowly, and it is easy for men to walk along the weir crest when the water begins to rise in flood, and to release the let-go gear; the shutters then fall on the crest and remain down during the floods. When it is necessary to raise the level of the pool above the weir, men lift the shutters by hand and attach the chains.

The under-sluices of this weir consist of only sixteen vents of 6 feet each in width and 10 feet high; the total length of the weir (including the under-sluices) is 2,572 feet, and, for this length of weir, the ventage of the under-sluices is abnormally small. The crest of the weir is 659·27, the floor of the under-sluices being 648·27, and that of the head-sluice of the canal 652·27, or 4 feet above the under-sluice floor. On the right bank of the river, where the canal takes off, there is a rock foundation for the head-sluice, but the under-sluices are in sand. The foundation of these is surrounded by lines of blocks sunk to various depths from 9 to 20 feet, and hearted with concrete. Some of the wells in the left wing wall are sunk to nearly 40 feet. The floor of the under-sluice, which is of rubble masonry 4 feet thick covered with 2 feet of ashlar, is 72 feet broad on the line of the axis of the river, with heavy pitching below. The under-sluice vents are arched over the piers, the arches, as in the Narora weir, being below the high-flood level. A high flood stands 17 feet on the under-sluice floor.

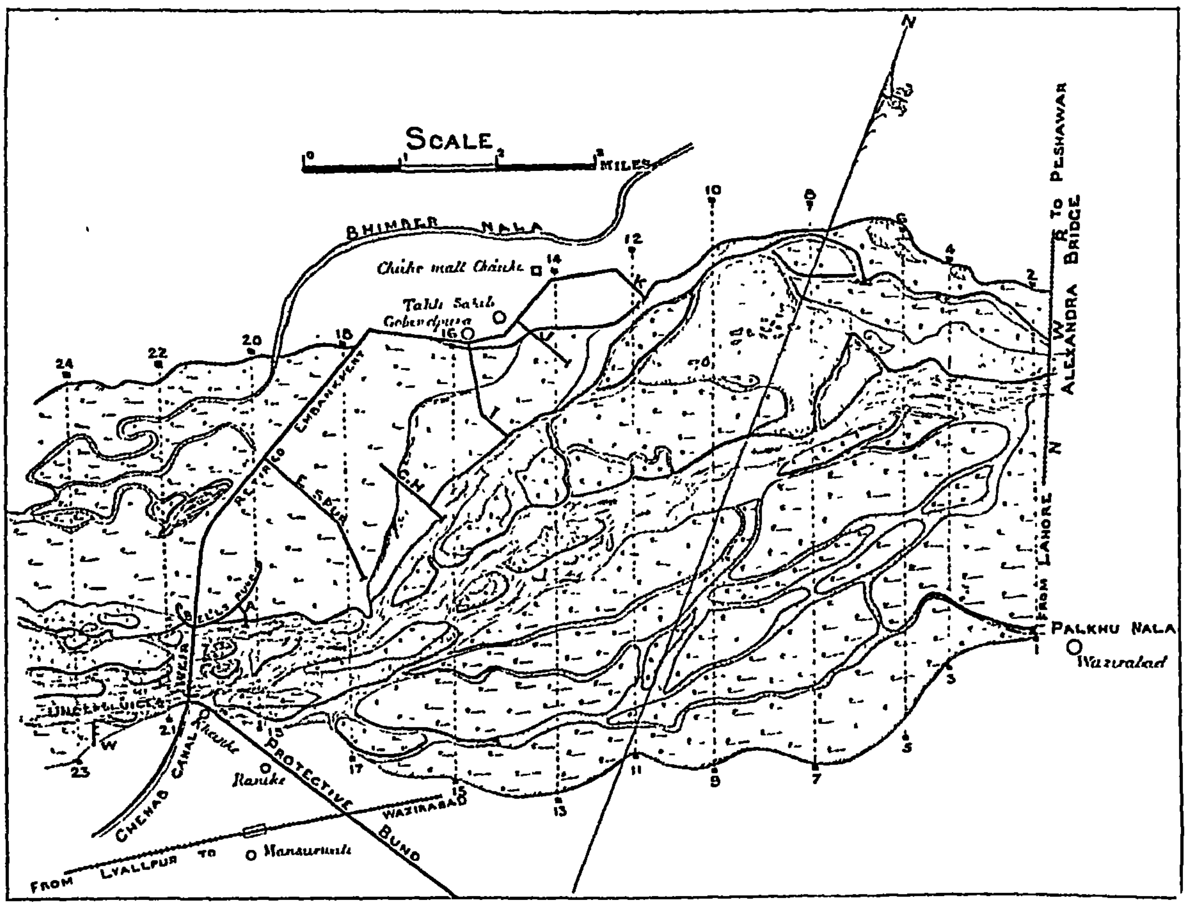
The head-works are protected on the left bank by an embankment, not dissimilar to that at Narora, which is connected with the weir and extends for seven miles above it. Groynes are thrown out at intervals from the embankment to check the velocity along the river face. In order to train the river it has been found necessary to construct permanent groynes with stone noses instead of tree spurs and sand bunds, as was originally proposed. The discharge of the river in high flood is only about 150,000 cubic feet a second, but the weir obstructs more than half the original waterway of the river, and the afflux is said to exceed

[1] "Roorkee Papers," by Major H. H. Jones, R.E., vol. iii., second series.

3 feet. The action on the weir slope is consequently very severe, even although the floods rise very slowly and fill up the reach below the weir before any severe strain is brought upon it.

There is not any large silt deposit in the canal and no dredgers are employed. There is an escape, with waterway rather greater than that of the head-sluice, in the second mile of the canal, by which some portion of the silt can be scoured out. The silt is of a very fine nature. The maximum velocity in the canal is $2\frac{1}{2}$ feet a second. The river bed above the weir has silted up to the level of the weir crest practically.

The head-works of the Chenab Canal in the Punjab are shown in the following sketch :—



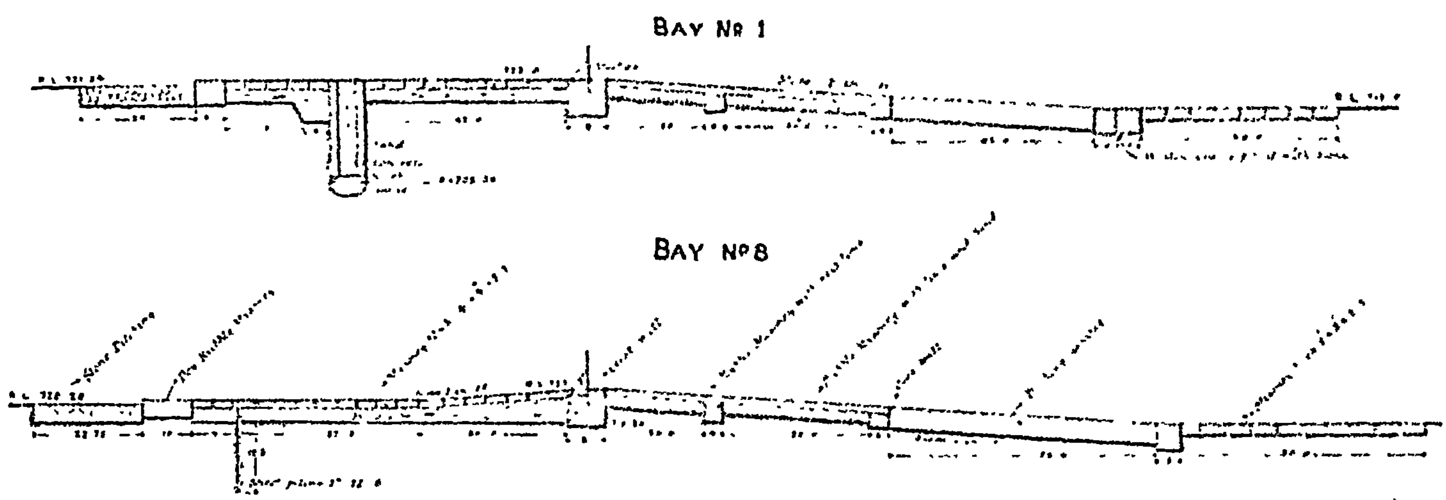
HEAD WORKS OF THE CHENAB CANAL.

The weir is constructed on the left bank of the river at a point where the full river bed may be said to be nearly $3\frac{1}{2}$ miles broad. The weir itself is only 4,000 feet long, and the water is compelled to pass over it by a system of training works. The right flank of the weir is protected by a " Bell's bund " both up and down stream. This bund consists of an embankment, paved on the river slope with stone, with a stone apron 60 feet broad and 4 feet thick, terminating in a round groyne head of stone of great strength. These bunds have stood all the floods without injury. The right flank of the weir was connected with the high ground, or permanent river bank, by a false bluff or retired embankment, $4\frac{1}{2}$ miles long, 12 foot top, with a river slope of 5 to 1 and inner slope of 3 to 1. On the left bank there was, originally, no embankment, but in 1892 the bank of the river was topped by a flood, and the protective embankment, shown on the sketch, was made. It was breached in 1903 and was strengthened. It is 15 feet crest,

with 5 to 1 and 3 to 1 slide slopes. The river slope is paved, and there is a horizontal apron of stone 40 feet by 4 feet. The crest is 5 feet above the flood level of 1903.

Soon after the works were originally constructed the river cut towards the north and threatened to outflank the retired embankment by cutting into the Bhimber Nullah, which flows not far behind the bank, and falls into the river a short distance down-stream of the weir. In 1899 spur E was made with a T head groyne. In 1900 this spur was gravely attacked, and it was determined to set back the head of it 1,000 feet and to erect spurs G H, I, J, and K. The heads of these spurs were aligned to the form of a long curve in the river; they were protected by stone heads of the form illustrated on page 160. In the high flood of 1903 four of these spurs were breached, and they have since been raised and strengthened: the crest is 15 feet broad and 5 feet above the highest flood level, the river and inner slopes being 5 to 1 and 3 to 1 respectively.

The weir across the Chenab river is an instructive example of a weir in fine sand which was, in the first instance, built to too light a section. The following sketch shows the weir as it now is:—



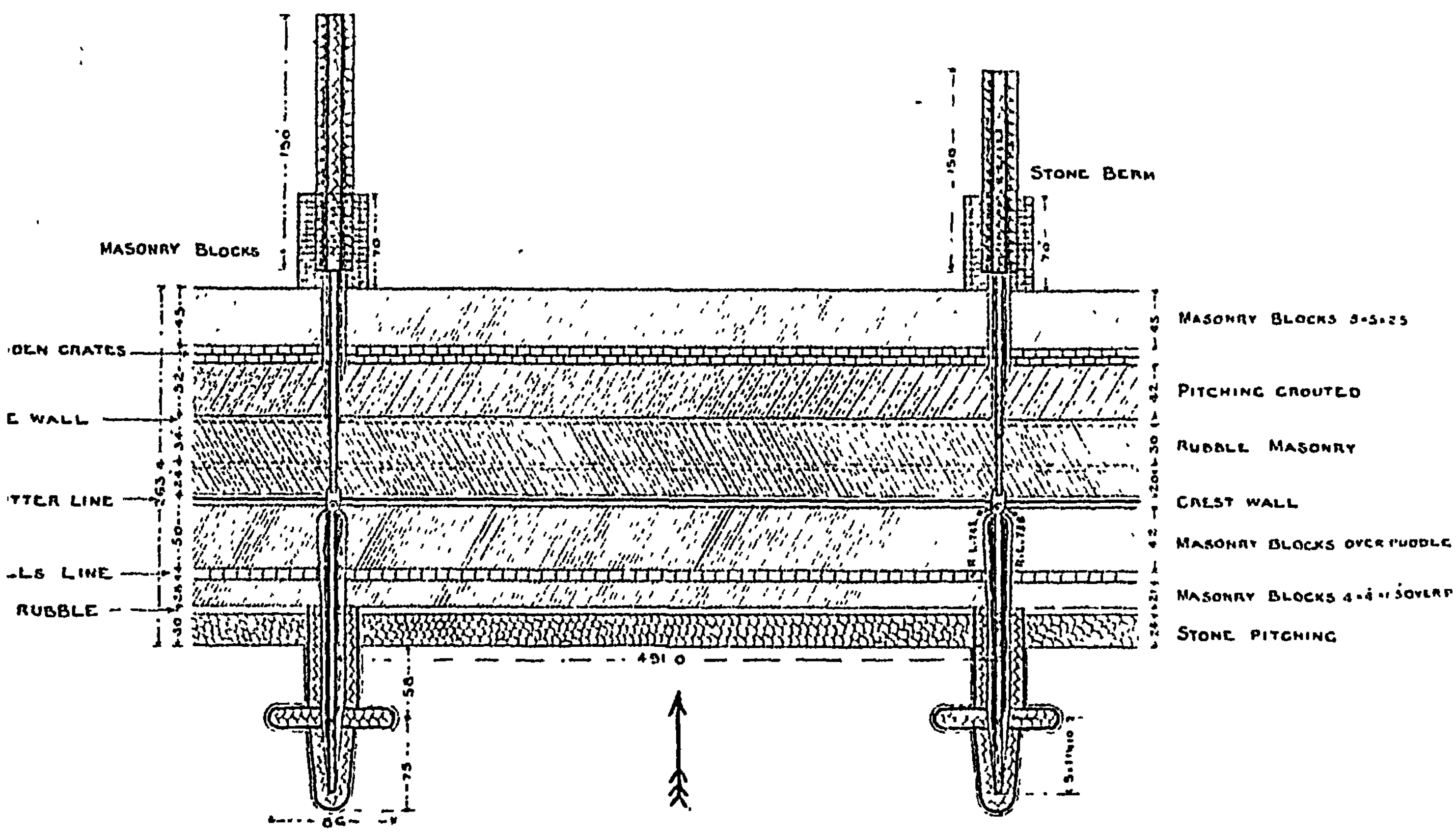
SECTIONS OF THE CHENAB WEIR.

The work on the up-stream side of the crest-wall has been added since the weir was built. There was, originally, only a reversed slope of stone pitching, triangular in section, with a base of about 24 feet, above the crest-wall. This has been removed, and the weir has been remodelled as shown in the upper of the two sections in all except one bay, which is as shown in the lower section. The crest-wall is a block of masonry 8 feet by 8 feet, and the base of it is only about 4 feet below the original bed level of the river: the crest of the wall being about 5 feet above the lowest summer level of the water in the river before the weir was built. The weir is divided into eight bays of about 500 feet each by masonry piers, which are raised above high flood level, as shown in the sketch on the opposite page. Above and below these piers are stone groynes. The up-stream groynes extend 195 feet above the piers, and the crests of them are 5 feet above high flood level. The down-stream groynes vary from 225 to 270 feet below the crest-wall, and are submerged entirely in high flood. These powerful groynes break the force of the current, which tends to be oblique to the line of the groynes.

Below the crest-wall the talus of the weir is formed at a slope of 1 in 15: the upper 60 feet is rubble stone in mortar with two small longitudinal walls; the lower 42 feet is dry stone 4 feet

deep, with the surface layer of stones laid on end, 18 inches deep, and grouted with mortar, quarry spawls being driven in to tighten up the work. At the toe of this talus there are two lines of crates 5 feet wide packed with dry stone, and below that a floor of large masonry blocks.

The first year (1892) after the weir was built it sustained no damage. In 1893 there was some subsidence, due, it is believed, to the severe action of the stream impinging on the groyne and scouring out the bed above the weir. In January, 1895, a settlement occurred in bay No. 1. The centre of it sank about 6 feet bodily, and from that point there was a perfectly uniform slope of crest, right and left, up to the original level near the piers, where there was no subsidence. There are 6-feet shutters on the crest of the weir; these were all up at the time,



Plan of One Bay of the Chenab Weir.

and there was some 4 feet of water standing against them. The river bed below was practically dry, and there was a head of something like 12 feet of water on the weir at the time of the settlement. The failure was due to "piping" under the weir. There were bad springs below all the bays of the weir, although only one actually failed.

In consequence of this failure the weir was strengthened as shown in the sections given above. A wide impermeable floor was laid above the crest-wall; a line of wells 42 feet in advance of the crest-wall was sunk 20 feet below the level of the crest, and the interstices were closed by piles. The floor between the crest-wall and the wells consisted of a layer of clay puddle, covered with concrete blocks 4 feet by 4 feet by 2½ feet with grouted joints. Up-stream of the curtain of wells the floor was extended for some 40 to 50 feet, ending in rubble pitching.

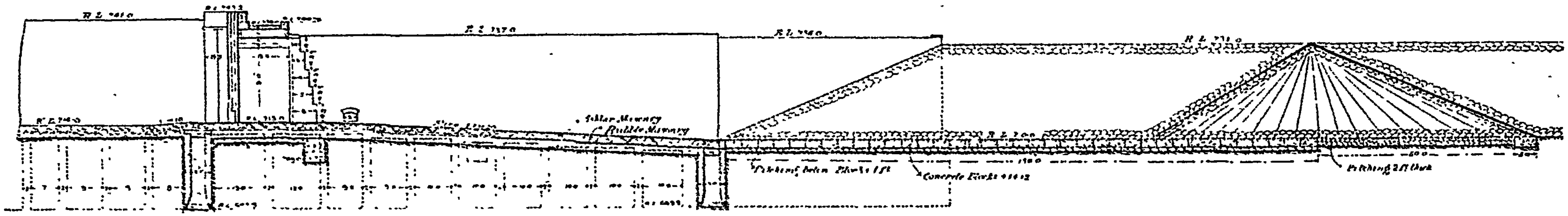
The Chenab weir in the great flood of 1903 was subjected to a maximum velocity over the

crest of 15·6 feet per second, and on the talus of the weir just in advance of the standing wall the velocity was over 30 feet a second. The weir, when the shutters are erect, may have to sustain a head of 12 feet, but ordinarily the head on it is 8 to 9 feet. The ordinary afflux due to the obstruction of the weir is 1·5 feet. But during the highest flood the heading-up was 3 feet, as determined by levels taken 11 miles above and 4 miles below the weir. The unobstructed water surface slope in this length of the river in floods would be 2 ft. a mile.

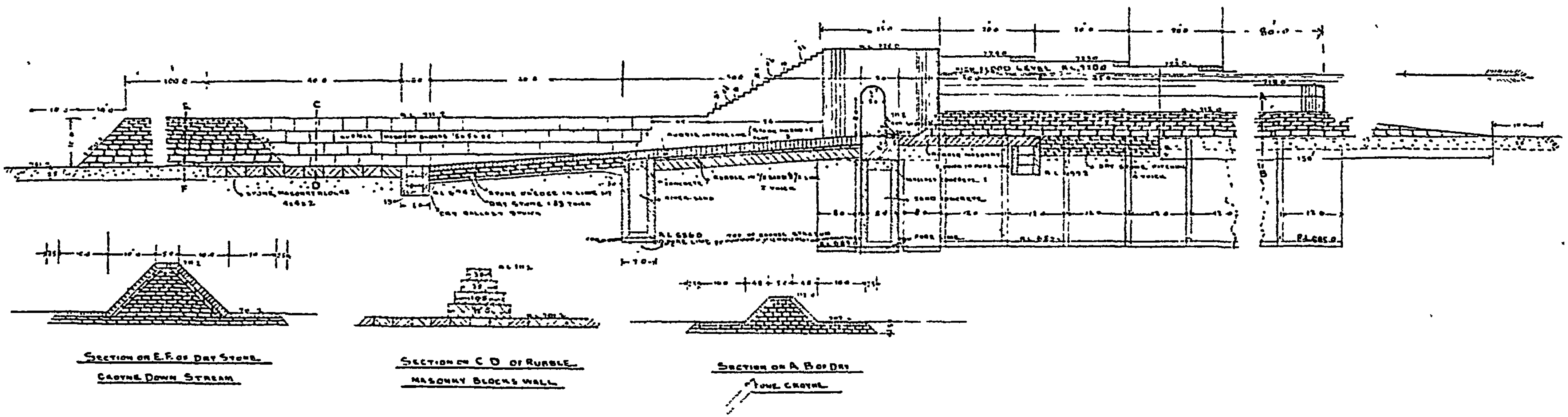
It is less difficult to construct a weir which is secure against being "blown up" (as the Narora weir was, page 161) by the hydrostatic pressure of the percolation water, than to design one which, without being abnormally expensive, is secure against the insidious effects of percolation water slowly undermining the work by "piping," as was the case in the Chenab weir. By this action the water, percolating through the sand, gradually assumes certain definite paths in which the velocity is sufficient to move the particles and to discharge them into the river bed below the weir. It is perhaps, theoretically, possible, by anaylsis of the "grade" of the sand (page 35) and by calculations based on the principles enunciated on page 162, to form an estimate of the probable velocity of percolation and to estimate whether this velocity will be sufficient to move the particles and produce "piping." But so many practical considerations, connected with the degree of consolidation of sand, its homogeneity, the silting up of the bed above the weir, affect the problem, that it must be admitted that it is mainly a matterof experience and judgment as to what width of impermeable floor is necessary to prevent injurious percolation which will cause "piping." The Chenab weir was remodelled and strengthened, in the manner indicated by the description and sketches on page 168, at great expense. The masonry block floor with puddle below it and the line of wells are an immense protection, of course, against the percolation of water below the weir. The measures adopted have been perfectly successful, but it may be questioned whether the line of wells was really essential and whether the weir would not have been sufficiently protected if the floor, above the puddle, had been laid as it was and subsequently grouted with cement into a solid water-tight floor. This would have more than doubled the length of the path of the percolation water below the weir. It should be noticed that the line of wells is only hearted with sand. There is no doubt that one of the most useful functions of a curtain wall is to check the currents following the under-surface of a floor, and, in this respect, a curtain wall is more effective in preventing "piping" than a mere prolongation of the floor, as it alters the direction of flow of the water and checks the flow of the sand.

Along the crest of the Chenab weir there are folding shutters,[1] somewhat similar to those on the Rupar weir on the Sirhind Canal (page 156). Each shutter is 6 feet high and 3 feet wide, and is supported by tie-rods, hinged to the masonry of the crest above the shutters. The upper end of the tie-rod is provided with a steel tie-pin for attaching to a trigger arrangement on the gate. When the gate is prostrate on the crest of the weir, the tie-rod lies in a guide groove, and it slides up this groove when the gate is raised. A slot in the face of the gate allows the tie-pin to pass through the gate when it is caught by the trigger. A crane of three-ton power runs on rails behind the crest shutters, but it is rarely used, as experience has proved that it is quite easy to lift the shutters by hand. Silt also accumulates, at times, on the track and interferes with the working of the crane. When $2\frac{1}{2}$ to 3 feet of water are passing over the crest three men can lift one shutter in every three or four minutes. The shutters were designed to be let go by a wire rope worked by a winch on each pier, but the arrangement is not used; it is found quite easy to lower the shutters by hand as quickly as the flood rises. When one shutter has fallen it

[1] Note by Mr. R. Egerton Purves, dated July 26th, 1904.



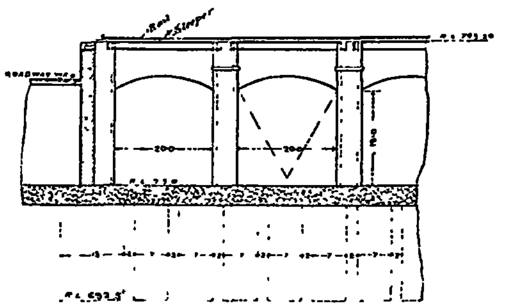
SECTION OF UNDER-SLUICES OF THE CHENAB WEIR



CROSS SECTION OF THE JHELUM WEIR.

gives a cushion of water for the next one, and the shutters are very rarely injured by falling on the masonry.

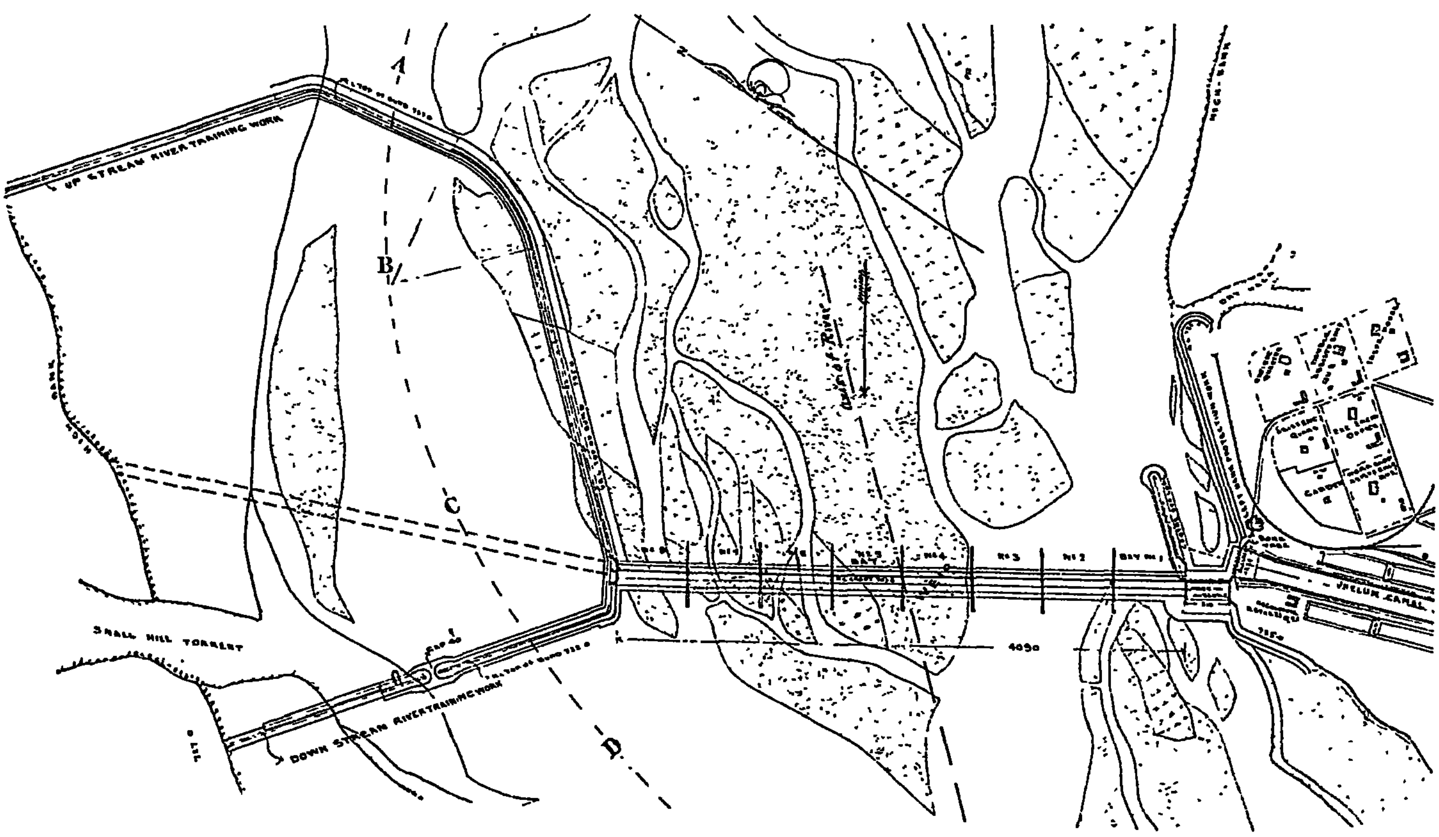
The under-sluices of the weir across the Chenab river consist of twelve vents 20 feet wide. The piers between them are 5 feet thick. The floor level is at R. L. 715·0 for a length of 15 feet, with a slope of 1 in 20 for 100 feet below. The drop walls are formed of wells sunk 23 feet below the level of the floor. The river bed above the sluices is paved for a width of 50 feet with hand-packed stone, and down-stream the protection consists of, first, 150 feet of concrete blocks 4 feet by 4 feet by 2 feet resting on a layer of small stone, then 50 feet of dry stone packing 2·0 feet deep, and lastly a line of concrete blocks 5 feet by 5 feet by 2½ feet. The entire down-stream protection is laid horizontal at R. L. 710·0, as shown in the section on page 171.



ELEVATION OF UNDER-SLUICES OF THE CHENAB WEIR.

The pier noses and floor are built with large blocks of ashlar. In the flood of 1903 two or three stones in the piers were shaken in their beds by floating timber. This has been the only damage sustained by the sluices since they were first built.

There are three sets of wrought-iron gates in each vent, one above the other. They run in separate cast-iron grooves. A description of these gates is given on page 191. All the gates can be lifted in seven hours.



PLAN OF HEAD-WORKS, JHELUM CANAL.

The highest flood on record was in 1903, when it was calculated that 75,000 cubic feet a second passed through the sluices. The velocity of approach was measured at 11·0 per second, and it is computed that the maximum velocity was 25·4 feet per second immediately in advance of the standing wave.

The weir across the Jhelum at the head of the Jhelum Canal is, in many respects similar to the Chenab weir: the sketch on page 171 shows the cross section of the weir at the first and second piers and the stone groynes which are erected both up-stream and down-stream to prevent currents parallel to the weir.

The total length[1] of the weir proper is 4,090 feet, the total width of the river at the site being about 1½ miles. It might perhaps be more correctly called a bar than a weir, as its main function is not to raise the level of the water in the river, but to keep the bed at the existing levels. The weir is divided into eight bays of 500 feet each by piers 10 feet thick. Stone masonry groynes divide each bay from the next. The line of the weir is inclined at an angle of 15 degrees to a line drawn at right angles to the axis of the river, and the face of the head regulator is inclined at an angle of 30 degrees to that axis. The right flank of the weir is connected with the high bank of the river by a strong stone-faced embankment, which is carried 3,000 feet up-stream, on a line parallel to the axis of the river, and is then curved round to meet the high bank. During the construction of the weir the water in the river, which never fell below 4,770 cubic feet per second, was passed round the right flank of the weir in the channel A B C D. This was the original main stream of the river. The operation of closing the bund at A was one of some magnitude: a most interesting account of the closure is given in the technical paper quoted in the footnote.

The right marginal embankment has a stone berm 60 feet wide and 4 feet thick at the toe of the slope. A second line of defence connects the down-stream groyne at the right abutment of the weir with the high bank of the river. It is intended to silt up the space lying between these embankments and the right bank of the river by admitting flood water into it by regulated openings in the up-stream and down-stream bunds. Along the crest of the weir there is a line of iron shutters 4 feet high and 6 feet wide, which are very similar in design to those on the crest of the Rupar weir (page 156). They can be raised or lowered by hand, but they can be lowered, when necessary, from the shore, or from the weir piers, by a wire rope working a trigger on the down-stream side of each shutter. The maximum flood passing over the 4,000 feet of lineal water-way of the weir is about 600,000 cubic feet per second. The highest recorded flood level before the construction of the weir was 720·20, in July, 1893: it is assumed that the obstruction caused by the weir and the restriction of the river will involve an afflux of 2 feet, making the flood level 722·00 over the weir crest. This gives a depth of 14½ feet over the crest and a mean velocity of about 9½ feet per second. A velocity of 10 and 11 feet has been observed through the under-sluices, which is considerably less than is recorded in some other similar works.

The under-sluices of the Jhelum weir consist of twelve bays of 20 feet and a fish ladder 10 feet wide. The floor of the under-sluices is at 701·00, that is, 6½ feet below the crest of the weir. The sluices are able to pass the whole volume of water that the river would discharge when it stood at the level of the top of the weir shutters (711·5). The under-sluices are closed by wooden needles, but cast-iron grooves have been fixed in the piers, so that, if it proves necessary, iron draw shutters, similar to those in the other Punjab weirs, can be inserted. The needle system is cheap, and, in this case, there is such an abundant supply of water in the river that there is no necessity to have water-tight gates; a little leakage will be immaterial. The needles are 11 feet by 5 inches by 4 inches. They rest, at the foot, against a 6-inch notch in

[1] "Punjab Technical Paper" No. 133, by Mr. H. J. Johnston.

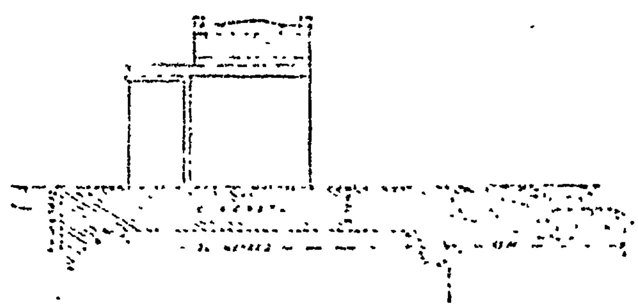
the floor, and, at the head, against an iron needle beam, which rests on the piers 8 feet above the level of the floor. The needle beam is 12 inches deep, and it carries a roadway 3 feet broad for manipulating the needles: it can be raised above high-flood level by a travelling winch. The sketch on page 174 gives the section of the under-sluice floor: the piers are 5 feet thick.

Two weirs have recently been constructed across the Rosetta and Damietta branches of the Nile below Cairo, to the section on page 174. The core wall was constructed under water by the grouting[1] system: it formed practically one continuous block of rubble masonry in cement, 20 feet high by 10 feet thick, right across the river. The weirs only retain a head of about 10 feet of water, and are abnormally strong structures. The river bed is of much the same nature as the Chenab bed—that is, it is fine sand and silt; probably there is more silty mud in the Nile bed than in the Chenab. The Rosetta and Damietta weirs are practically water-tight: there is hardly any filtration perceptible below them. The sketch of the Rosetta weir shows the "Beresford's filter" which has been adopted. This system was originally adopted, at Mr. J. S. Beresford's suggestion, on the weir across the Jhelum at Rasul: it tends to prevent the action of water in undermining a talus or floor. The system consists of an inverted filter laid on the sand. The bottom layers are formed of a substantial wedge of very fine stone ballast broken to the size of peas; above that is small rubble, then larger rubble, and then the pitching. The fine ballast or gravel allows any filtration water to pass freely, but, by dissipating the velocity, prevents the passage of any particles of sand. This stops the undermining action of springs.

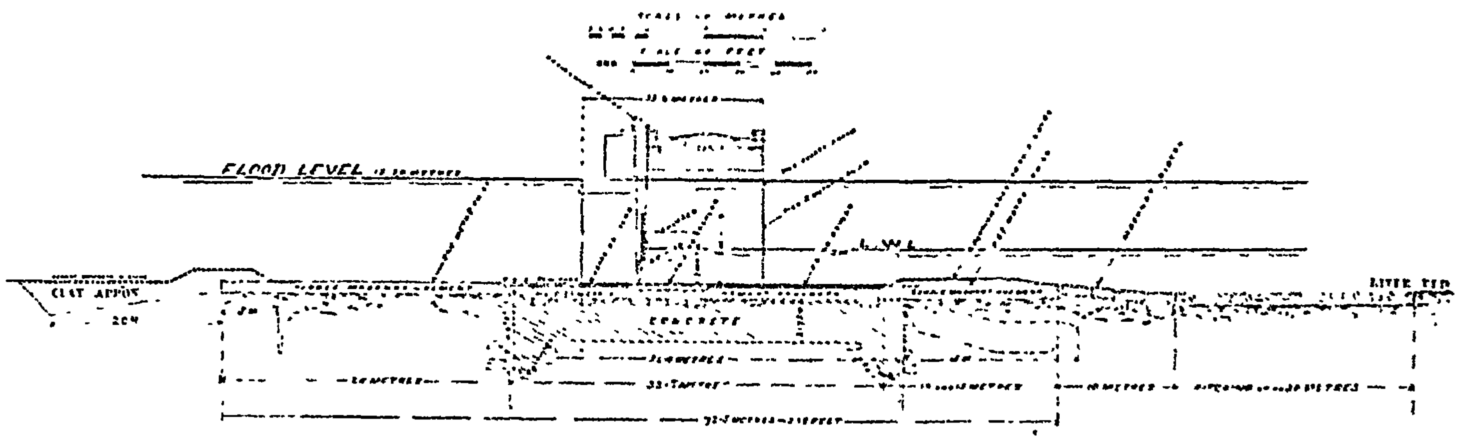
The Agra Canal weir at Okla is an example of what can be done in the way of constructing a weir without any depth of foundation, even in extremely friable soil, provided that there is ample heavy material available to resist the high velocity and great erosion in the lower slope, and provided also, and this point is of great importance, that the flow of the stream can be constantly maintained at right angles to the weir. Strong currents parallel to the face of light foundations are most disastrous. In this case it has to be borne in mind that the floods rise slowly, and there is less danger of any sudden alteration in the main currents. The stability of this weir has no doubt been greatly increased by the deposits of silt which have occurred above it, and which have tended greatly to prevent any probability of serious percolation immediately under the weir, which might undermine it. In cases where dangerous parallel currents are not likely to occur, a 6-inch deposit of silty mud in the channel of a river above a weir is a better security against under-scour than foundations 50 feet deep. It has been maintained that, in those cases where the chief danger to a weir is from under-scour and not from parallel currents, the true measure of the security of a weir in a permeable bed is the distance through the soil which a current of water would have to travel before it could rise up below the weir, and that it is of little consequence whether masonry is laid horizontally on the river bed or sunk vertically below it, so long as currents passing through the soil below the structure are exposed to the friction of the same length of passage. This view appears to be sound, but it is essential to attach to the application of the principle the conditions that the weir must be protected from longitudinal scour on the face and toe, that it must have sufficient weight to resist the horizontal pressure of the head it supports, and also sufficient weight to oppose the upward pressure on the base of the foundations which that head may produce; and further, that the surface of it, which is exposed to erosion, shall be of material sufficiently hard and sufficiently heavy to resist that erosion. For the mere purpose of making a weir water-tight, and so saving water in the dry season for irrigation, deep foundations, if carried down to an impermeable stratum, are, of course, of great value; and in deep sandy beds they have a

[1] Paper by Sir Hanbury Brown in "Proceedings of the Institution of Civil Engineers," vol. clviii., 1904.

certain value, as they impede the amount of percolation below the weir to a certain extent, but their value in this respect is not as great as may be supposed. If the bed of a river is in deep coarse sand the water will percolate through it below a weir from the higher to the lower level, in spite of almost any depth of foundations; and, if the bed of the river immediately above a weir has been staunched by silt deposits, the percolation, although checked, will still take place from a point higher up the river where the bed has not been so staunched, and, although the percolation may perhaps be reduced by deep foundations, it will not in such a case be stopped. This may be seen in several Indian weirs in deep coarse sand. In the Sone weir, for instance, the silting above the weir has been very marked, and the weir itself is very fairly water-tight; but in the dry season, when water is very valuable and when every effort is made to keep all



Original Section of the Delta Barrage.



Delta Barrage as Reconstructed

the shutters in the weir as tight as possible, so that every available drop may be pressed into the canals, there is a considerable stream in the river two or three miles below the weir which is formed of water which has percolated through the deep sand on which the weir is founded. The foundations in this case are 8 feet below the river bed, and it is questionable whether the amount of water which passes below this weir would have been affected if the foundations had been 30 feet deep, or, indeed, if the weir had been founded on the river bed instead of being depressed into it; but the depth of the foundation in this case has been fully justified as a protection against the possibility of dangerous parallel currents.

The principle of trusting to the width of base rather than to depth of foundation, which has been successfully adopted at Okla, finds an almost equally striking exemplification in the barrage across the Nile below Cairo. This fine work, which is, strictly speaking, a regulating bridge,

and not a weir, is founded on the extremely friable soil of the Nile valley, composed of alternate beds of fine river sand and alluvial mud of a finer and more soluble nature than that on which the Nárora and Okla weirs are built. Borings which were made into it to a depth of 100 feet showed that the soil did not improve with the depth, and that it melted[1] almost like sugar when brought in contact with water.[2] The barrage consists of two regulating bridges placed across the two deltaic branches of the Nile at the point where they bifurcate from the single stream of the river. The floors of these regulators are at the level of the river bed, and the obstruction which the work offers to the floods of the river consists of the piers and the flank locks. The foundations of the barrage were originally designed as shown in the upper of the two sketches, and were supposed to have been constructed in that manner with the addition of a sloping masonry talus 49 feet (15 metres) broad and $8\frac{3}{4}$ feet (2·66 metres) thick: but it is doubtful whether the floor below the superstructure really was built $12\frac{1}{3}$ feet (3·75 metres) thick as shown in the sketch; and the talus, if it was constructed, was almost entirely swept away before 1886, as only traces of it could be found when the reconstruction of the floor was executed. It had been intended to put a head of 14 feet 9 inches on the barrage, but it was quite incapable of bearing the pressure. The leakage was great even at a much smaller head,

COST OF INDIAN HEAD-WORKS.

Name of Work.	Approximate Full Discharge of the Canals.	Cost of the Head-works.
	Cubic Feet per Second.	Rupees.
BENGAL:		
Orissa Canals	6,000	45,41,545
Midnapore Canal	1,500	5,20,633
Sone Canals	6,400	23,26,229
UNITED PROVINCES:		
Ganges Canal[3]	8,000	4,36,270
Lower Ganges Canal	5,000	41,42,408
Agra Canal	2,000	11,79,086
Eastern Jumna Canal	1,800	17,00,757
Betwa Canal	1,000	11,20,703
PUNJAB:		
Western Jumna Canal	6,400	4,94,037
Bari Doab Canal	6,500	7,57,347
Sirhind Canal	8,200	13,64,297
Chenab Canal	10,800	41,21,552
Jhelum Canal	3,800	31,10,061
Sidhnai Canal	2,400	2,59,286
MADRAS[4]:		
Srivaikunthum Anicut System ...	2,500	2,46,161
BOMBAY:		
Bhatgarh Reservoir and Nira Canal	450	21,18,783
Mutha Reservoir and Canals ...	—	28,37,717

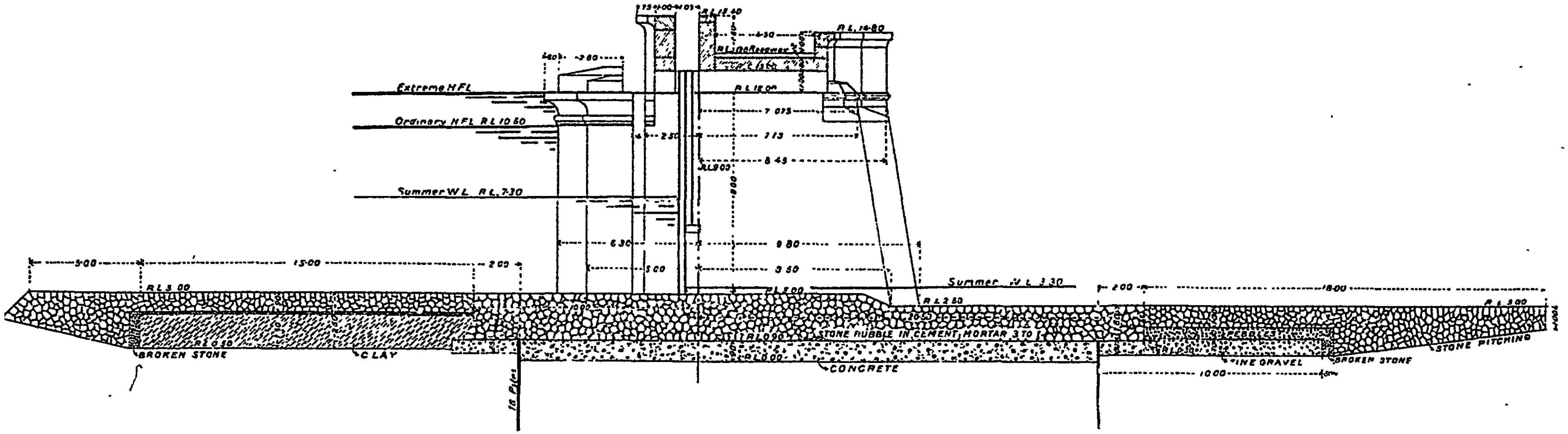
1 "Minutes of Proceedings of the Institution of Civil Engineers," vol. lx., p. 374.
2 "Note on the Nile Barrage," by Colonel Sir Colin C. Scott-Moncrieff, K.C.M.G., R.E., Cairo, 1890.
3 This canal has a temporary weir or dam constructed each year.
4 The correct figures for the older Madras Canals—the Godavery, Kistna, Cauvery, and Penner—are not available.

and the work showed many signs of weakness. The floor was ultimately[1] reconstructed substantially, as shown in the lower one of the two sketches on page 176. The actual width and thickness of the new work was varied in places, according to local circumstances and according to the quality of the work found in the old floor: in one place, for instance, the new floor laid on the top of the old one was increased from 4 feet to 10½ feet (3·25 metres) in thickness, and the lower floor, which is shown 15 metres broad in the section on page 176, varied in width from 10 to 15 metres. Subsequently the piers and foundations were grouted[2] with cement through a series of bore holes driven right through the piers, and the barrage now holds up with safety a head of 10 feet, and would probably do more. The total width of the work, inclusive of block and rubble pitching, extends in some parts to more than 400 feet, the greatest width of the Narora and Okla weirs, which sustain a maximum head of 10 feet, being 250 feet. In the case of the Delta Barrage the width of the impermeable masonry floor is 220 to 240 feet, as compared with 155 feet in the Narora and 72 feet in the Agra weir under-sluices. It is interesting to compare the weirs mentioned in this chapter with the Assiut and Zifta Barrages which have recently been constructed across the Nile. The Assiut Barrage has 111 spans of 5 metres (16½ feet), and the Zifta Barrage has fifty spans of 5 metres. The former is designed to hold up a head of 2½ metres (8¼ feet), and the latter 4 metres (13 feet) of water. The sections of these barrages are shown in the Plate on page 179.

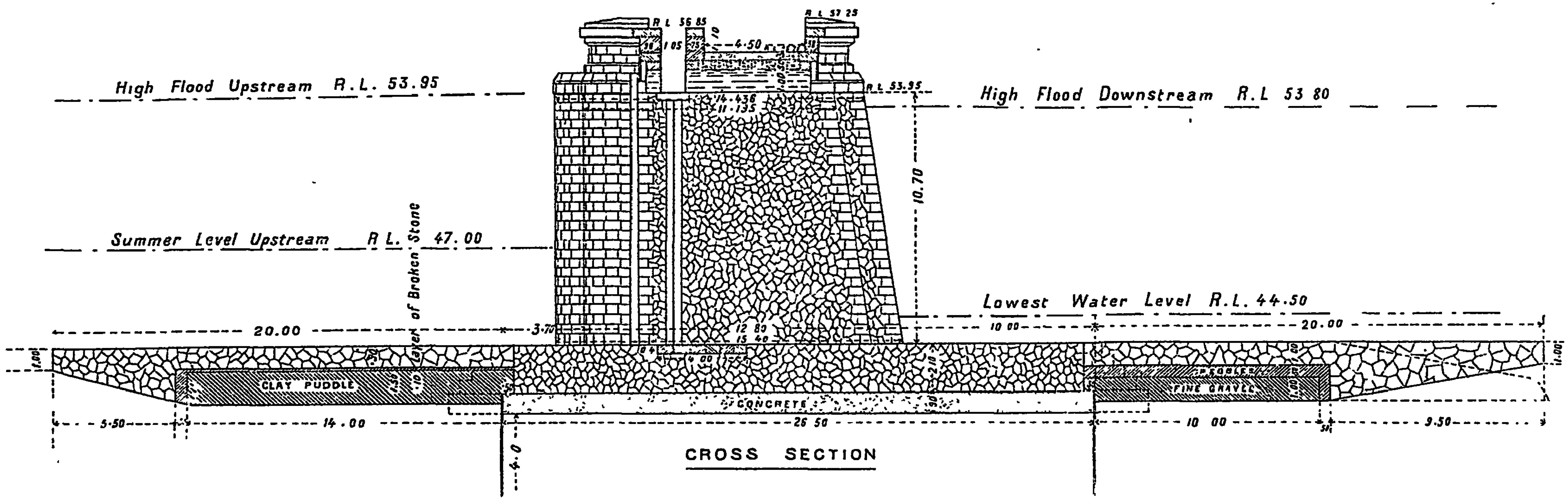
The cost of the head-works of irrigation systems varies enormously, according to the nature of the river in which they are constructed. The table on page 177 shows the actual cost (up to the end of 1902—1903) of the head-works of the chief perennial canals of India. The figures show the cost of the works only, and do not include the charges for establishment, tools and plant, &c., which would increase the amounts by about 25 per cent.

[1] "The Delta Barrage," by Major (now Sir) R. Hanbury Brown. Cairo, 1902.

[2] See Paper by Sir Hanbury Brown in "Proceedings of the Institution of Civil Engineers," vol. clviii., 1904.



SECTION OF ZIFTA BARRAGE DIMENSIONS IN METRES.



SECTION OF ASSIUT BARRAGE DIMENSIONS IN METRES.

CHAPTER XI.

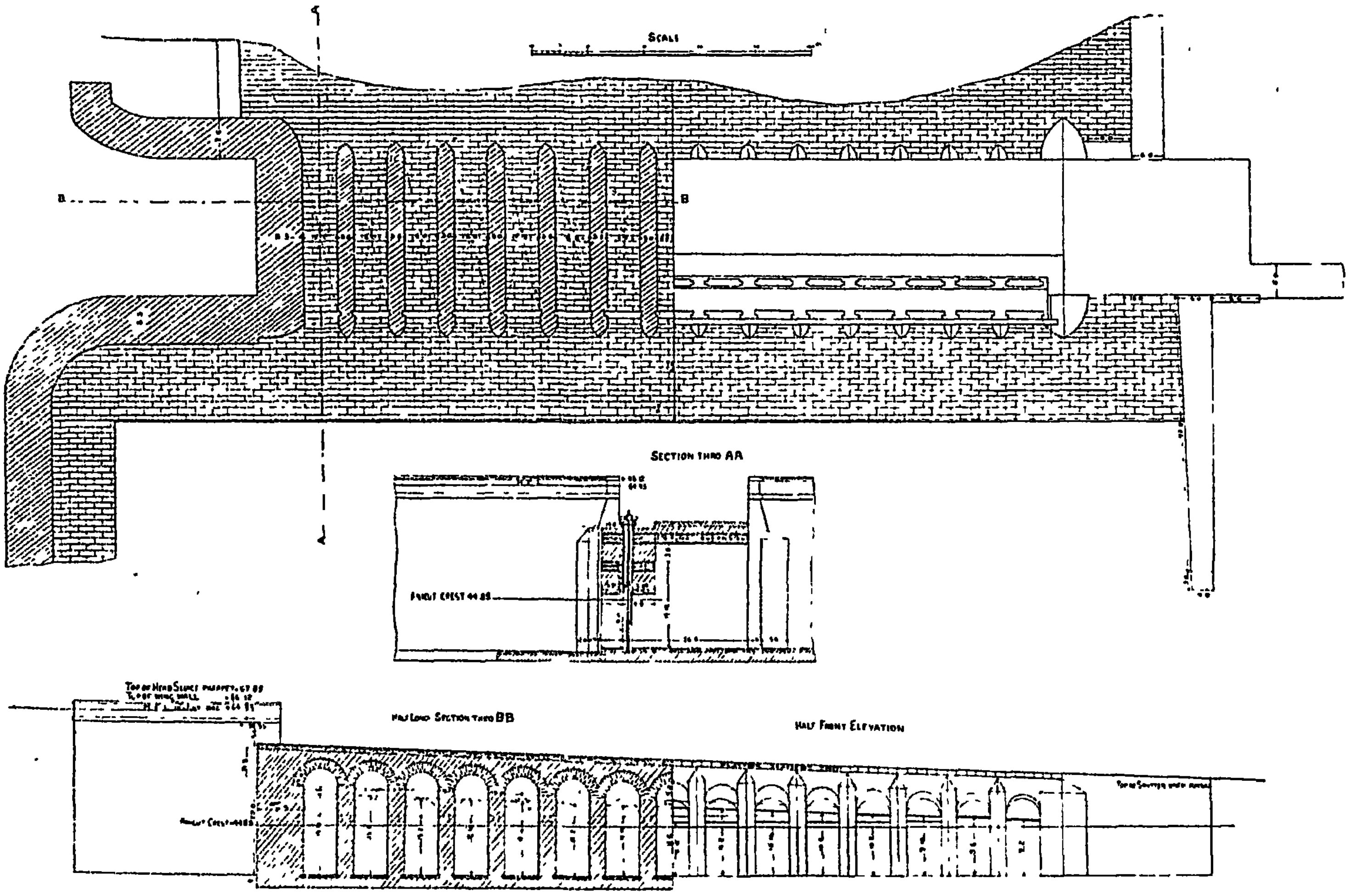
GATES OF UNDER-SLUICES AND WASTE WEIRS. MOVABLE DAMS.

Principles of the Construction of River Weirs—Central Sluices in a Weir of doubtful Value—Size of Under-sluices—Baulks and Needles in Under-sluices—French Shutters in Orissa and Midnapore—Hydraulic Brake Shutters of Sone Weir—Hydraulic Opening Gear—Fouracres' Double-tumbler Shutter—Under-sluice Gates in Upper India—Gates on the Barrage at Cairo—Counter-balanced Gates in Madras—Under-sluice Gates of the Bhatgarh Dam—Automatic Waste Weir Gates—Gates of the Bhatgarh Waste Weir, Bombay.

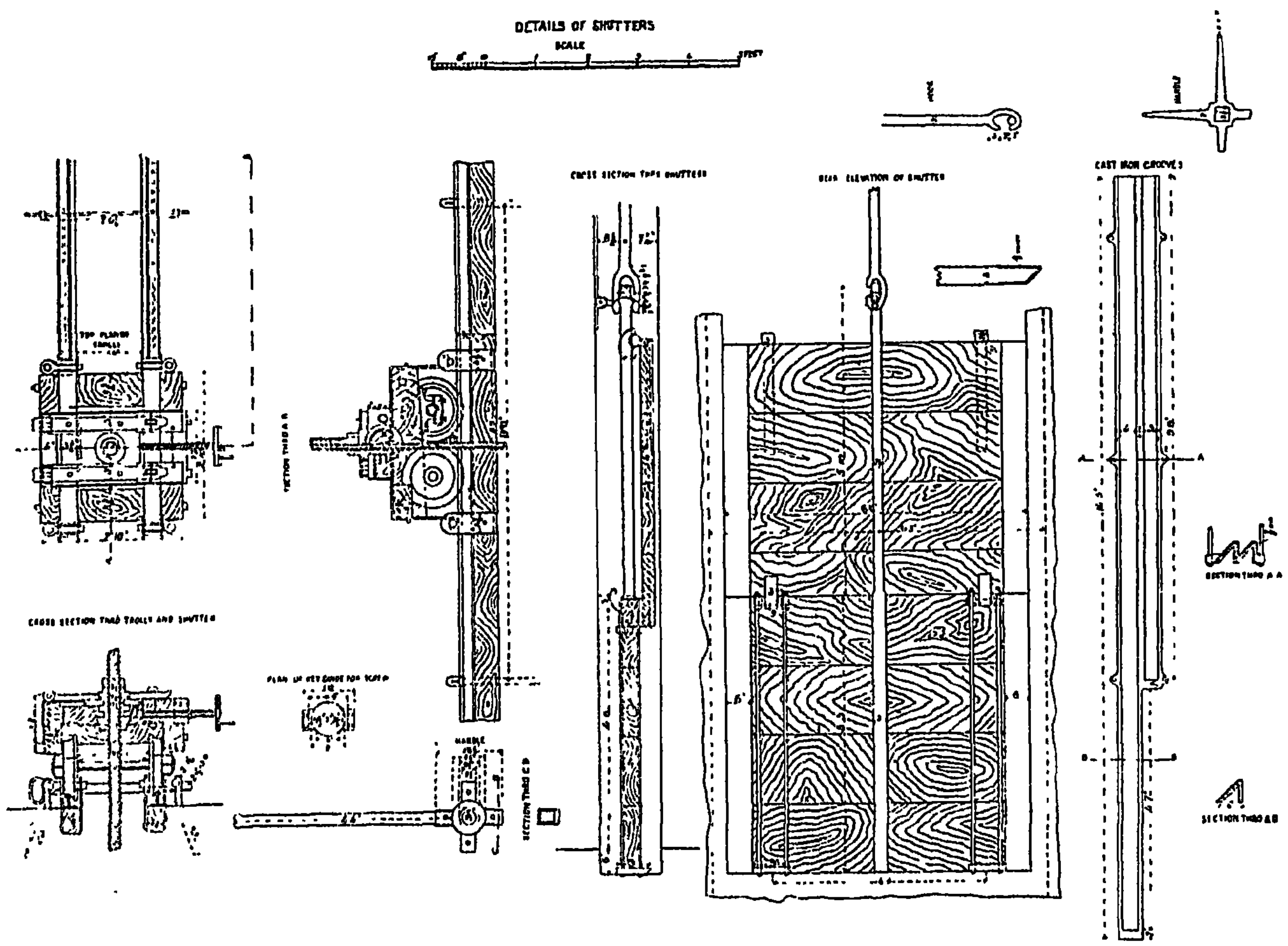
In the foregoing chapters detailed descriptions of several under-sluices have been given. It is most difficult to lay down any general rules for the construction of these important adjuncts to a river weir; indeed, it is doubtful whether there are any accepted principles to regulate the dimensions which it is desirable to give to under-sluices. The earlier examples[1] constructed in Madras were made with vents about 6 feet broad, and raised to only about half the height of the flood, but recent practice has been to increase the width of the vents to 20 feet (or even more) and to make the openings clear above high flood. It is nearly always necessary to have a set of under-sluices below the offtake of a canal, to prevent the accumulation of silt immediately in front of the head-sluice: and it used to be held desirable to have an additional set in the centre of long weirs; it is now considered that central sluices are not of much practical value. The weirs of the future will probably be less in height above the canal bed and be all fitted with movable shutters on the crest. Broad and strong floors are essential in all under-sluices, and, as a rule, breadth of floor is more efficacious than deep curtain walls. It is better to prevent pooling below a floor by surface protection than to guard against the danger of it by deep-seated foundations. It is always desirable to have a long river wing between the weir and the under-sluice floor: this wing may advantageously be carried to a greater length below the line of the weir toe than the under-sluice floor itself. The crest of this wing should be above the level of the weir crest at the upper end, but it should slope down-stream to 2 or 3 feet in height at its lower end. The velocity through the sluices is always greater than that over the weir, and there is a tendency for a strong circular eddy to be formed where the two currents join: a long river wing separates these currents and assimilates the velocities. The under-sluice floor should generally be at the level of the deep bed of the river, but, if it is possible to put it lower, without inordinate expense in laying the foundations and in other points of construction, an advantage is gained.

It has been thought that the ventage of under-sluices in any particular case should bear some proportion to the discharge of the canal which takes off above them, and, if any rule can be deduced from existing examples, it should apparently be that the ventage of the under-sluices below the level of the weir crest level should not be less than double the ventage of the head-sluice; but in this matter the practice varies greatly. In some Madras examples which have been successful, the ventage in the under-sluices is about the same as that in the head-sluices above them. Similarly, if the ventage of under-sluices be compared with the total obstruction offered by the weir, which is another standard which has been suggested, it will be found that the same great difference of practice exists and that no rule can be deduced. The amount of

[1] "Lectures on Irrigation Works in India," by Colonel F. H. Rundall, C.S.I., R.E., 1876, No. V.



UNDER-SLUICES OF THE BEZWADA WEIR OR ANICUT.



DETAILS OF SHUTTERS OF THE BEZWADA ANICUT.

ventage required is less in the case of rivers with small slopes. The following table, which is only approximately correct, gives some statistics of the under-sluices of different weirs:—

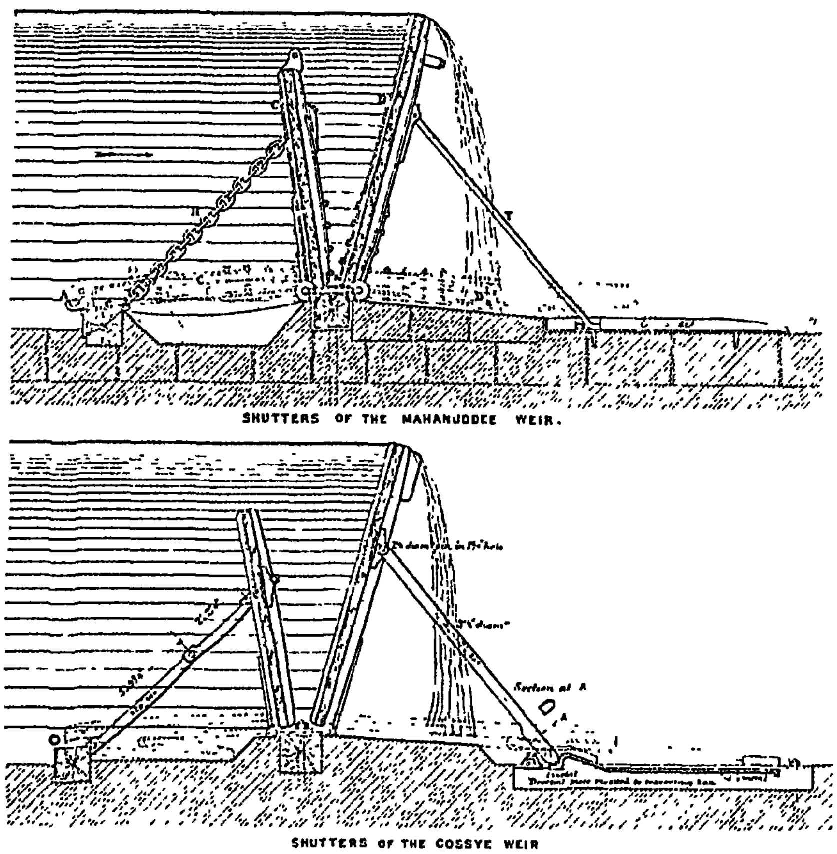
VENTAGE OF UNDER-SLUICES.

Name of Work.	Approximate Total Length of Weir and Sluices between Abutments.	Average Height above Original Bed.	Lineal Feet of Ventage in Scouring Sluices.	Area of Waterway of Head Sluices below Level of Weir Crest.	Area of Waterway of Scouring Sluices below Weir Crest.	Proportion which the Area of Scouring Sluice bears to the Total Obstruction offered by the Weir.	Remarks.
	Feet	Feet.		Square Feet.	Square Feet.		
Upper Coleroon Weir	2,800	5 / 7	111 / 48	?	555 / 336	1 to 12	Eight sets of sluices distributed; canal on one bank. Two sets of sluices; no canal.
Mahanuddee Weir ...	6,400	12½	640	720	8,000	1 „ 9	One set of under-sluices, and one set of centre-sluices; canal on one bank.
Sone Weir	12,500	8	1,152	2,340	9,216	1 „ 10	Two under-sluices; one set of centre sluices; canals on both banks.
Ravi Weir (Madhupore)	2,800	3	240	1,035	1,320	1 „ 6	One set of sluices; one canal.
Sutlej Weir (Rupar)	2,700	9½	240	1,462	2,280	1 „ 10	„ „ „
Jumna Weir (including the island) at head of W. J. Canal	3,400	6	547	—	3,850	1 „ 5	One set of under-sluices on each bank, and a canal on each bank, but one is never used. The weir is diagonal to the stream; no accurate comparison can be made in this case.
Ganges Weir (Narora)	2,200	10	304	1,470	3,040	1 „ 12	One set of under-sluices; one canal.
Jumna Weir (Okla) ..	2,600	10	96	504	1,056	1 „ 23	„ „ „
Lower Jhelum Weir	4,500	?	240	?	1,512	About 1 to 11	„ „ „
Lower Chenab Weir	4,500	?	240	?	2,000		„ „ „
Upper Chenab Weir	4,500	?	245	?	1,520		„ „ „

The earlier examples of under-sluices with small vents of only 5 or 6 feet in width were generally worked with wooden draw-gates and sometimes with baulks dropped into grooves. Plate on page 181 shows the under-sluices of the Kistna weir at Bezwada in Madras (constructed in 1854—55) and the method used for working the gates. The system of baulks has been abandoned in all recent examples as too clumsy, and, in most cases, far too slow for safety; as, in the event of a rapid rise in the river, it is not possible to get the baulks taken out in time. In some cases needles are suitable: especially in rivers where no rapid manipulation is necessary. Both needles and draw-shutters are used in the under-sluices of the Cavour Canal, on the Po in Italy: in that case the draw-shutters have a bar of flat iron attached to them pierced with holes at close intervals: the shutters are raised by long levers with studs at the end which fit the holes in the flat iron; but the greater portion of the ventage of these under-sluices is manipulated by a movable needle dam. The needles bear against skeleton gates which are released simultaneously by gearing in the piers. A long rope is strung through the eyes on the tops of the needles, and they are picked up with it after the sluice is open. The under-sluices of the Madaya weir (page 123) and the Jhelum weir (page 173) are regulated by needles, and there are two small weirs (Eden Canal and Madhuban Canal) in Bengal which are regulated in the same way.

In the Mahanuddee weir (Plate on page 142) the under-sluices consist of vents of 5 feet each only, with wooden draw-shutters: these are manipulated by a wooden derrick which is placed on the low piers of the sluices and moved from vent to vent as necessary. The arrangement is very primitive. But the centre sluices of this weir and the under-sluices of the head-works of the Midnapore Canal, on the Cossye river, consist of movable dams which are a modification of those introduced by MM. Thénard and Mesnager on the river Isle in France.

The movable dam[1] consists of two rows of wooden shutters placed back to back, as shown in the sections on this page; both rows of shutters are very strongly hinged to a beam bolted down to the flooring of the sluice; the back, or down-stream, row of shutters is about 18 inches higher than the front row. The shutters of the Mahanuddee weir are about 7 feet wide; the upper ones are 7 feet 6 inches and the lower ones 9 feet high. There are seven shutters in each bay of the movable dam or centre sluices, and ten bays or vents, each 50 feet wide; each bay is separated from the next one by a stone pier 5 feet thick, on which the gearing for working the shutters is fixed. In the Cossye weir there are only three bays of 50 feet; each bay contains eight upper and eight lower shutters, the upper ones being 6 feet and the lower 7 feet 9 inches high. The front shutters fold down on the floor up-stream; the back shutters down-stream. A beam in front of the upper shutter is bolted down to the floor in such a position that the top of the shutter is just in a line with the up-stream face of the beam; the top of this beam is about 3 inches below the top of the central beam, so that the shutter slopes slightly downwards from its heel when lying on the floor. The lower ends of the retaining chains are fastened to the beam in front, and the upper end to the castings on the back of the battens of the front shutter. These chains are not fixed in a plane at right angles to the face of the vertical shutters, but diagonally, both sloping inward towards the centre of the shutter; the object of this is to prevent the upper half of the chains falling on the top of the lower half under the shutters, and preventing them from going down flat on the beam G. The chains now fall of their own accord, as the shutters descend, into a loop; a slight hollow is purposely left in the floor, in which this loop lies, so that, when the shutters are down, they



UNDER-SLUICE SHUTTERS USED ON THE ORISSA AND MIDNAPORE CANALS.

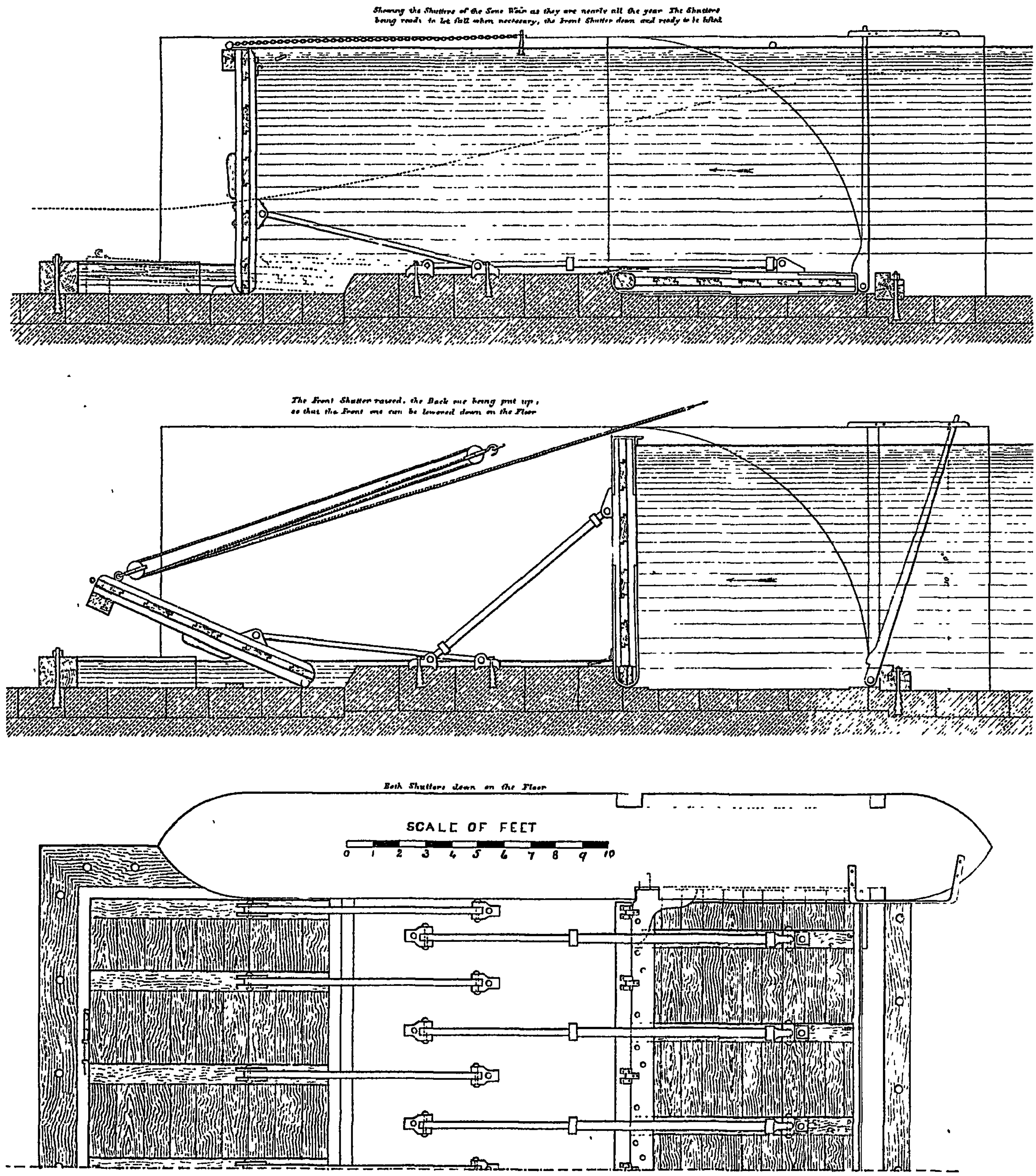
[1] Taken from the author's paper in vol. lx., "Proceedings of the Institution of Civil Engineers," 1880.

are clear of the chains. The front shutters being down, hooks, attached to the bar in front of each shutter, are revolved by the bar until they catch the castings bolted to the face of the shutter.

When the Mahanuddee shutters were first put up, it was thought that they would lift of their own accord if these hooks were thrown out of gear when the stream was flowing through the sluices; but this only happened occasionally, when some bank or impediment directed the force of the stream under the shutters; and it was found that, even if the shutters were lifted an inch or so, the stream sometimes pressed them down again on the floor instead of lifting them. Another difficulty was also met with. After the shutters had been down perhaps for a few months, small water-worms used to construct cells between the shutters, the beam and the floor—cells which stuck the shutters down so tightly that force was necessary to break the crust. For these reasons the following plan has been adopted :—A rod of iron, about 2 inches in diameter, is fitted along the face of the beam in front of the upper shutter; at one end of this rod a handle is arranged, so that the rod can be revolved about one quarter of a revolution. The rod bears in the castings fixed to the face of the beam. On this, under the centre of each shutter, a cam is keyed, which, as the bar revolves slightly, lifts the shutter as soon as the hook is out of gear. The seven cams fixed to each rod to lift the seven shutters in each bay are set at slightly different angles, so that, as the rod revolves, they come into operation on the shutters one after another, and the shutters rise in the same order as soon as the stream catches them.

The back shutters, which are erected by hand after the front shutters have been raised and the current has been stopped, are always used to retain the pressure of the water when the movable dam is closed. When they are erected they stand inclined at an angle of about 15 degrees down-stream. They are supported at the back by struts, one of which is hinged to the batten at the back of each shutter at about three-eighths of the height of the shutters from the top. To the first shutter in each bay two struts are fitted. Between all the shutters a T-iron is hinged to the castings fixed on the centre beam, which has a strut hinged to it similar to those on the shutters. These last struts and T-irons are altogether independent of the shutters; they are loose from them, and are put up separately after the shutters are raised. The heels of all the struts rest, when the shutters are up, in the lugs of the iron shoes, which are bolted down to the floor. The shutters are raised one by one by men standing on the floor below. They first lift the shutters—there being, of course, little or no water on the floor—and support them by the first-mentioned struts. After any two contiguous shutters are up, the strut between them is raised, the root of the T-iron is inserted between the shutters, and they both bear against the head; a joint fairly water-tight is thus formed. To let the back shutters fall when a flood is expected, a bar, arranged to slide in guides on the floor close to the heels of the struts, acts in the same manner as the bar used in M. Chanoine's falling dams in France. Studs are welded on to it at intervals, which catch the heels of the struts as the bar is drawn along the floor by the gearing fixed in the pier. These studs are so fixed that the shutters fall one after another, the studs coming into gear with each pair of struts consecutively, the shutter which has the two struts L attached to it being the last to be let down. As the first shutter falls, the second is supported by its own strut, and the neighbouring T-iron strut at the joint between itself and its neighbour. When the sixth shutter is let down, the seventh, were there not two struts attached to it, would be twisted by the force of the stream; it is to prevent this that double struts are attached to the last shutter.

As there is generally little or no water on the apron when the sluices are opened, men can nearly always walk about behind the shutters as they are being let down; indeed, the back shutters



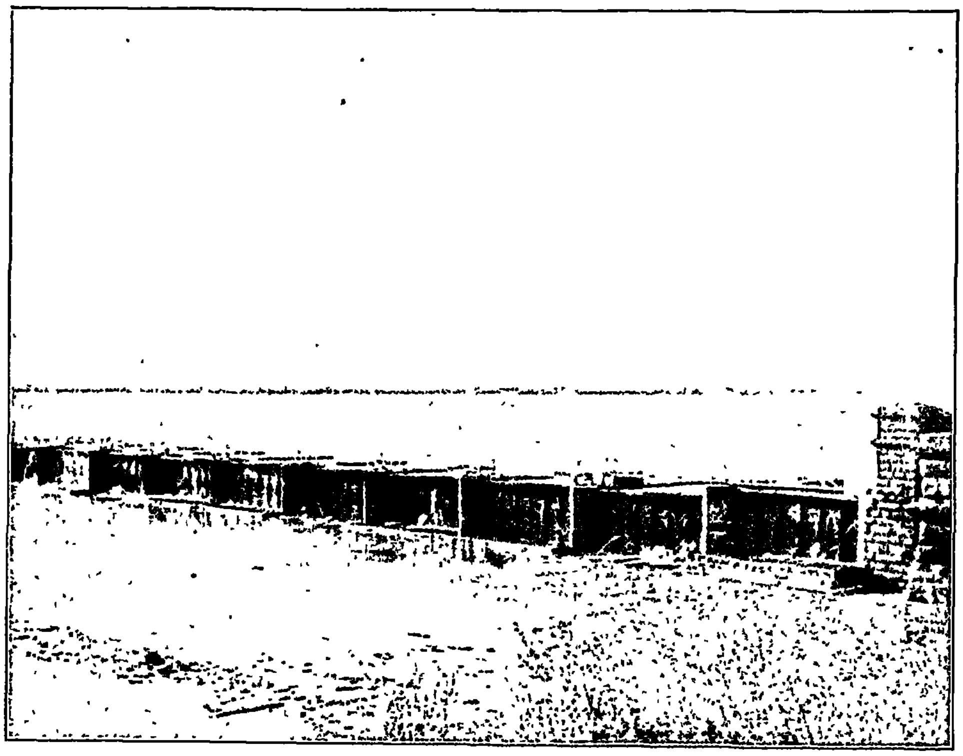
UNDER-SLUICE SHUTTERS OF THE SONE WEIR.

are not unfrequently let down by men with crowbars pushing the struts out of the lugs on the shoes; or sometimes the men knock the struts out of the lugs by a wooden beam which they jump against them.

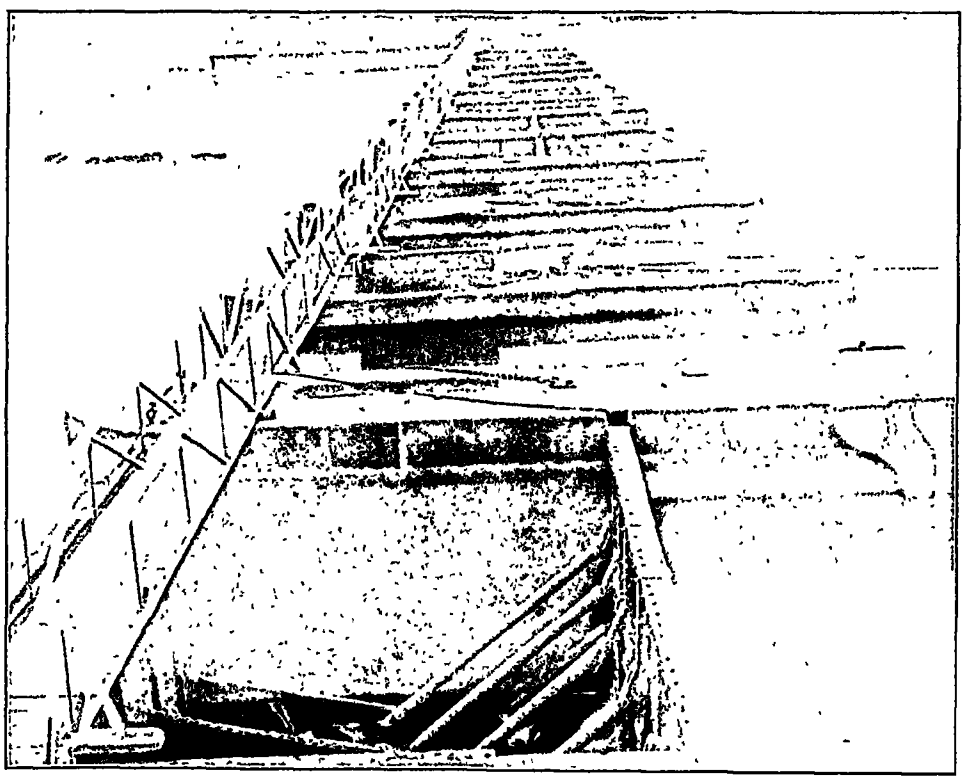
This form of movable dam has one great disadvantage: this is the severe shock which the retaining chains have to bear. The chains were constantly breaking, both in the Mahanuddee and Cossye weirs. On the Mahanuddee there are now $1\frac{1}{4}$-inch stud chains; they were at first $\frac{7}{8}$ inch. On the Cossye weir the constant breaking of the chains gave so much trouble that the engineer in charge has substituted folding links (lower figure, page 183). On one occasion the front beam was pulled up from the floor. The strain on each chain of the shutters of the Cossye weir, 6 feet high by $6\frac{1}{4}$ feet broad is about sixteen tons. This kind of shutter has never been raised against a greater head of water than about 6 feet 9 inches. The front shutter is only used when the level of the river has fallen to at least 6 feet above the floor of the weir, and frequently the engineers hesitate to use the shutters until it has fallen lower. The mode of working this form of dam is simple. Supposing the shutters to be flat on the floor, and the stream running through the sluices, if it is desired to lift the front shutters, the bar in front of the upper beam is made to revolve by the handle on the pier, the hooks are released, and the cams on the bar raise the shutters, one by one, a few inches above the beam; the stream then rushes beneath and throws the shutter violently up into place. When all the front shutters are up the men go below on the floor of the sluice and lift the back shutters by hand, having first drawn back the disengaging bar. The struts are placed in the lugs, and the back shutters are then ready to receive the pressure of the water.

It has been found that in a dam constructed on this principle, 500 lineal feet of shutters can easily be lowered in one hour with a head of 6 feet of water, and that with a similar head an equal length can be closed in twenty-five minutes; that three men standing on the floor are sufficient to knock away the back struts, with safety to themselves; that the back shutters are not damaged as they fall on the floor, because sufficient water escapes as each shutter falls to form a cushion for the other shutters to fall into. Twelve men are necessary to lift each of the back shutters into position.

In the Sone weir (Plate on page 185) each of the under-sluices is fitted with a movable dam, designed by Mr. Fouracres; each sluice is divided into twenty openings of 20 feet 7 inches wide; the piers between the openings are 6 feet thick and 32 feet in length, and the tops of the piers are 10 feet above the bed of the river, that is, 2 feet above the crest of the weir wall, which is 8 feet above the sluice floor. About the centre of each opening the level of the floor is raised 9 inches, and thicker floor stones are laid; the object being partly to have heavier stones for the lower edge of the shutter to oscillate against, and partly to form a recess, so that the shutter may lie snugly on the floor. Each opening is fitted with two shutters; the up-stream one is 21 feet 3 inches in length, and 9 feet 9 inches high. This shutter is pivoted at its lower edge, and turns on two strong cast-iron gudgeons working in sockets built into the piers. The shutter being 8 inches broader than the width between the piers, has, when vertical, a bearing of 4 inches on either side against each pier; but this has been found unnecessary, as the telescopic struts are sufficiently rigid to withstand the pressure; and when the packing in the hydraulic brakes becomes worn, the shock against the pier injures the masonry. The piers are recessed 5 inches deep for the extent required to enable the shutter to oscillate freely between the horizontal and vertical positions. At the back of the shutter six struts are fitted, which are the peculiarity in this system; they answer the double purpose of supporting the shutter when vertical, and of breaking the force of concussion against the piers when the shutter is suddenly raised with a 9 feet depth of water running through the sluices. There are six



Under-sluices of the Sone Weir.



Under-sluice Gates, Sone Weir.

[*To face page* 186.

back-stays to each shutter; each consists of two cast-iron brackets, the first firmly attached to the stone floor, the other to the shutter; to the lower bracket is hinged an iron bar, $2\frac{3}{4}$ inches in diameter, and to the upper bracket a wrought-iron pipe, $3\frac{1}{2}$ inches internal diameter; the bar is inserted into the pipe, and the two thus form a telescopic strut. On the lower extremity of the bar is a collar which, when the shutter is vertical, is in contact with a ring shrunk on the end of the pipe; the pipe thus forms a rigid strut supporting the shutter at the back. On the rod, which is $\frac{3}{4}$ inch less in diameter than the pipe, are shrunk two guide rings, and above the upper ring is fixed leather packing similar to that of a hydraulic ram; this packing makes the head of the rod into a piston, which, when exposed to the force of the water, fits tightly into the tube. In the pipe are five small holes $\frac{3}{16}$ inch in diameter; the lowest one is about 4 inches above the leather packing of the rod when the shutter is horizontal and the telescopic joint drawn out; there is a group of three holes at the top of the pipe, a little above the leather packing when the shutter is vertical and the telescopic joint shut up; the fifth hole lies midway between the top ones and the bottom one. The action of these backstays is as follows:—When the shutter is down and the telescopic joint drawn out, the water running through the sluices enters and fills the pipe through the $\frac{3}{16}$-inch holes, and flows probably past the piston, for the leather packing becomes loose as the rod is drawn out; the pipe is then full of water. As soon as the shutter begins to rise, and the telescopic joints consequently begin to shut, the leather packings, being opposed by the water in the pipes, become tight, and the water can only find means of escape through the small $\frac{3}{16}$-inch holes; its efflux is therefore much retarded, and a brake is placed on the motion of the shutter: the resistance increases as the piston passes the first hole, and attains a maximum after the piston has slid past the second hole, and the shutter comes up gradually to the vertical position, the water being expelled in a jet from the three topmost holes. When the shutter is lying down on the floor, and the telescopic back-stays are extended at full length, the holes in the pipes rest on indiarubber buffers secured to the back of the shutters. This completely closes the holes and prevents sand or silt accumulating within the pipes. At first the holes were placed on the top of the pipes, and they became clogged by sand.

A vertical bar, with a catch at the lower end, worked by a handle on the pier, is fixed to retain the shutter horizontally until it is required to be lifted.

The down-stream shutter is 20 feet 7 inches long and 9 feet 7 inches high, fitting between the two piers without any recess; on the up-stream side of this shutter seven tension bars are hinged, first to brackets bolted to the floor above the shutter and then to the shutter itself. The shutter oscillates about the centre of the bracket pin, and the tension rod about the centre of the pin of the bracket which is fixed to the floor; so that, when the shutter falls down-stream, the lower part slides along the floor towards the fixed bracket, and finally sinks into the horizontal position shown by dotted lines (Plate on page 185). At the back of every alternate shutter a trough is formed by a curb of ashlar 12 inches high, which stretches across from nose to nose of the piers; this trough remains always full of water, and forms a cushion to break the fall of the shutter should it be necessary to let it down when there is no water on the apron. After every alternate shutter has fallen there is sufficient water on the apron to break the fall of the intermediate one.

The tension-rod is hinged to the shutter a few inches below the centre of pressure when the water is level with the top of it, so that when the river rises slightly, the centre of pressure is soon raised sufficiently above the centre of oscillation of the tension-rod to overcome the friction of the lower edge of the shutter on the floor; the shutter then falls into the horizontal position, and the flood is free to pass. A chain at each end retains the shutter, if necessary, against

any head of water. Pieces of kentledge are fastened to the front of the shutter to keep it steady and to prevent it from being raised and knocked about by the stream flowing over it. The shutter, when lying on the floor, is inclined slightly upwards, the top being a few inches higher than the heel; the stream impinges on the inclined surface of the shutter, and thus presses it down tightly on the floor with a pressure varying with the velocity of the stream. The shutter remains steady so long as the water is flowing with a velocity of more than 2 feet a second. The usual velocity is about 17 feet a second. The kentledge is only wanted in case the water below the weir rises nearly level with that above it, when the velocity would be so small that the shutter might float and be damaged by the stream. In each of the upper shutters is a small sluice, which can be opened by hand, to fill the space between the two shutters with water, and thus place the pressure on the lower shutter. In front of the up-stream shutter a groove is cut from top to bottom of the piers, into which logs of timber can be dropped when repairs are necessary, or in case any accident should prevent the shutters from being lifted.

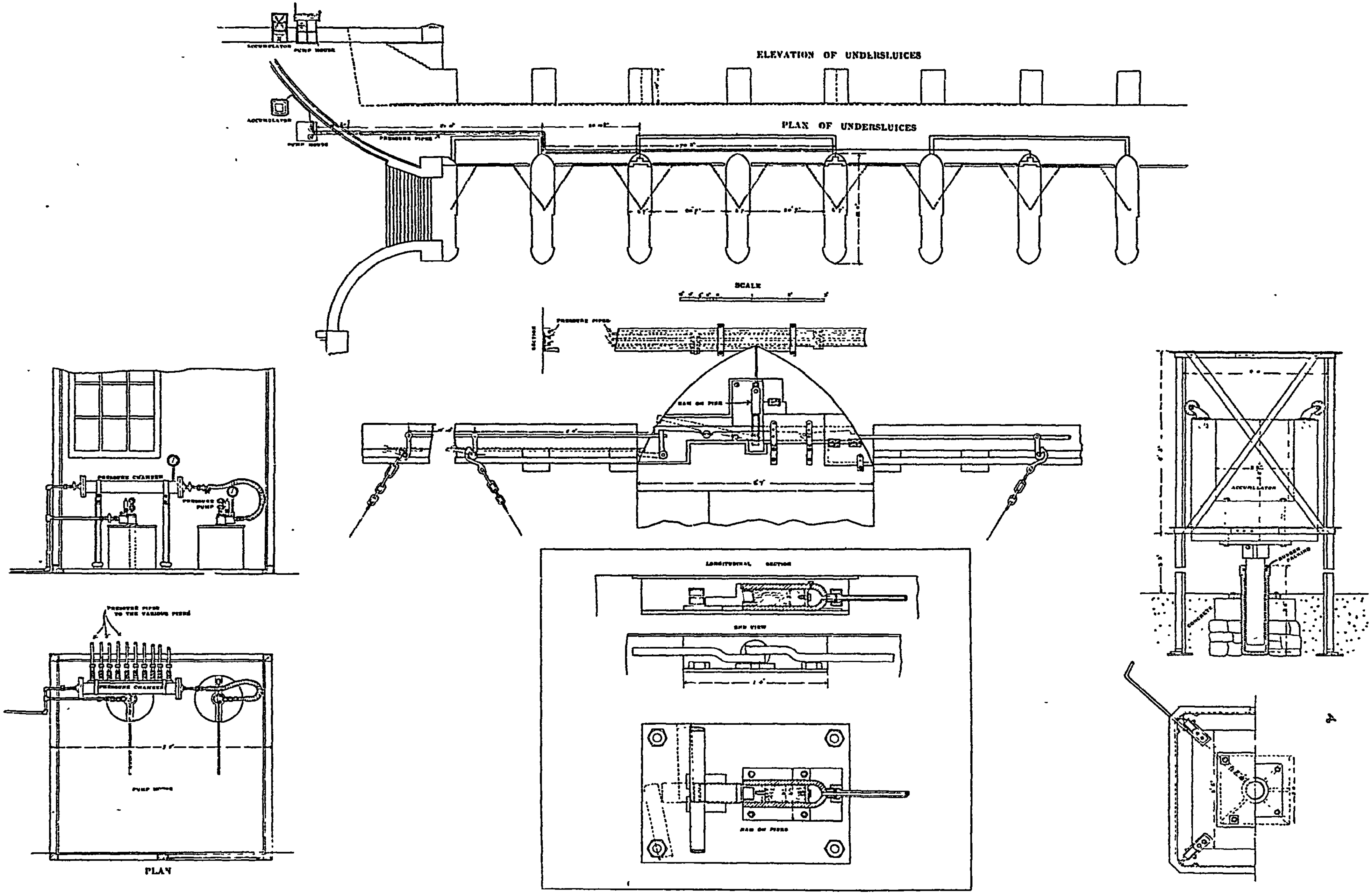
During the dry season the water is retained in the weir-pool by the back shutter, which is secured in position by two chains; one end of each of these chains is fixed to a stud in the centre of the pier, the other end is slipped into a let-go gear on the top edge of the shutter. When floods are expected, the back shutter gear can be let go, so that, should the flood rise suddenly, the shutters will upset of their own accord and let the water pass freely. This is not, now, usually done, but the shutters are released by the hydraulic gear which is described below.

At any time when it is desired to close the under-sluices, a light portable foot-bridge is run across on the top of the piers, which are then probably only a few inches higher than the water above the weir, so that men can easily pass along the whole length of the dam. In the next place a hook, having at its upper end a cranked shoulder fitting into a lever attached to the pier, is placed under the angle-iron which is fixed on the top edge of the front shutter; the lever is then drawn tight by a light threefold tackle attached to the pier; when this has been done on each of the piers and all is ready, the catches which keep the shutter down are withdrawn, the men draw down the lever with the tackle until the upper edge of the gate has been lifted about 8 inches, and the stream then raises the shutter slowly into the vertical position, the hydraulic brakes preventing any shock.

It has been found in practice on the Sone weir, that these shutters can be lifted, against a head of 10 feet of water, that is, when the water in the pond above the weir is level with the top of the piers; the greatest head against which other shutters on any other weir have been lifted is believed to be about 6 feet 9 inches only. It is a sight worth seeing to watch a stream of water, 20 feet broad and 8 or 9 feet deep, flowing with a velocity of 17 to 20 feet a second, suddenly checked by a single gate 20 feet long by 10 feet deep. The water, when the shutter reaches the vertical, rises in a wave 1 foot or 2 feet above the top of the shutters and piers, and flows over for a few seconds before it sinks to the mean level of the stream.

When the front shutters have been raised, it is advisable to put up the back shutters at once, and to refold the front shutters on the floor; because, should a flood come down unexpectedly, the back shutters will be ready for any contingencies, and also because there is always danger of silt, sand, stones, and rubbish collecting before the front shutters.

To raise a back shutter the tackle used for hauling down the levers of the front shutter is again employed; one block being hooked to an eye-bolt on the upper edge of the back shutter, and the other block to a rag-bolt in the side of the pier, four or five men haul on the tackle and pull the shutter into a vertical position. When both shutters are up, the men proceed to lower the front one. The valve in the front shutter is opened, and the space between the two filled with water; the back one now retains the whole pressure, and the front shutter simply rests in



HYDRAULIC LET-GO GEAR OF THE UNDER-SLUICE SHUTTERS OF THE SONE WEIR.

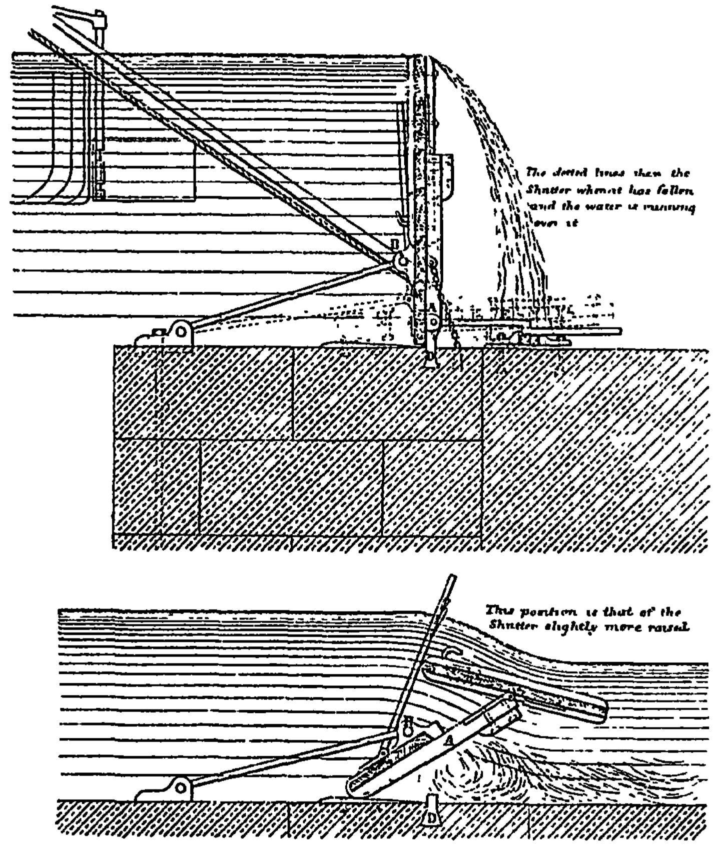
the water, the pressure on each side of it being equal. The front shutter is then pushed up-stream by two men on each pier pressing it down with a pole or boat-hook until it rests on the floor, so that the catches can be brought into gear, and it is safely fixed ready to be again lifted. Should it be found necessary to upset the back shutter when the water above the weir is below the top of it, and when the centre of pressure is consequently below the axis, a boom or spar, with an eye-bolt at one end, is applied against the top of the shutter on the batten next the pier, and the tackle before used is hooked into the eye-bolt at the other end of the spar which is then boomed out against the shutter until it falls. It takes about half-an-hour to fully manipulate each vent of the under-sluices.

In the practical use of these shutters two disadvantages had become apparent. The first was that the upper shutters, when lifted with the full head (10 feet) of water, came up with more shock than was desirable. The second was that the back shutters could not be regulated with such nicety that the pool could be kept up to the full level. A strong wind would cause waves which made them fall when the pool was several inches below its full level, or some other cause would send one of them down. The result was that the pool was lowered and the discharge of the canal materially reduced. When a back shutter did fall it was necessary to let the pool run down to about 6 inches below its full level before the corresponding front shutter could be raised again, as it was not thought safe to lift it. These disadvantages came frequently into play when little flushes came down the river, and the consequence was that the pool was very rarely at its full level. Both of the difficulties have now been overcome. The first one by the simple arrangement of a partial needle weir between the two shutters. Grooves have been cut in the piers so that one baulk can be let down in them about 5 feet above the floor and another placed at the level of the crests of the piers. These baulks span the opening between two piers. Vertical needles are placed against them so as to partially close the vent. The baulks and needles are run into place in about fifteen minutes. The flow through the vent is obstructed to a certain extent, and, when the front shutter is lifted, it has a cushion behind it which entirely stops all shock, and it is now easily possible to lift any shutter against the full head of 10 feet or even more. The second difficulty has been overcome by the arrangement illustrated on page 189. On each alternate pier a small hydraulic ram has been fixed which acts on two levers. These levers control a let-go gear, working on the chains which hold up the lower shutters, in each of the two bays which lie on either side of the pier on which the hydraulic ram is placed. Each ram has an independent pressure pipe which is in communication with the pressure chamber on the abutment of the weir. This chamber can be kept under pressure, if required, from the neighbouring accumulator. But, as a matter of fact, the pressure is usually applied direct from the hydraulic pumps which are in the pressure house. Each pressure pipe has a cock, near the pressure chamber, which controls the pressure in it. It is thus possible for the operator, standing in the pressure house, to hold all the shutters up to any level he thinks proper, and to release any particular pair of shutters that he wishes by admitting the pressure to the pipe leading to the hydraulic ram concerned. The arrangement has been found to work excellently in practice and to be most convenient. The pool is now frequently held up to 2 or 3 inches above its full normal level of 10 feet, and it is possible to open vents remote from the head-sluice and thus to keep still water near the canal. Under the old system a single shutter near the head-sluice might fall, and the result was the introduction of sand into the canal.

Another form of under-sluice shutter or movable dam was constructed and subjected to experiment by Mr. Fouracres. It has not fulfilled successfully the essential condition for all dams on Indian weirs, namely, that they should be capable of being lifted without shock against

a head of 8 feet or 10 feet of water, but it is nevertheless worthy of attention, for it possesses several advantages as regards lifting against a head of water over the system of M. Chanoine,[1] to which it is in some respects similar.

Each shutter consists of two parts. The lower part is made of two wooden battens, A, 4 feet long, attached at their lower ends by a longitudinal plank about 2 feet broad. The upper shutter is hinged to the top of the battens of the lower one in the centre of its height; it consists of planks and battens with a counter-balance weight and hook at its lower edge. The lower shutter is hinged by casting B to a tie-rod 5 feet long, the up-stream end of which is hinged to another casting, firmly bolted to the cut-stone floor of the weir. This casting B is attached to the lower shutter at such a point that, when the shutter is in the position shown in the upper figure, the centre of pressure of the water on the whole shutter is about 3 inches or 4 inches above the centre of the castings B. Short chains are attached to the heel of the lower shutter, to prevent it riding over the stops D, which bear against the heel of the gate when it is in the vertical position. To the heel of each lower shutter two wrought-iron bars E are hinged, which, when it is erect, catch into castings on the floor, and will hold the shutter against any head. There is a draw-bar on the floor by which these bars can be released.

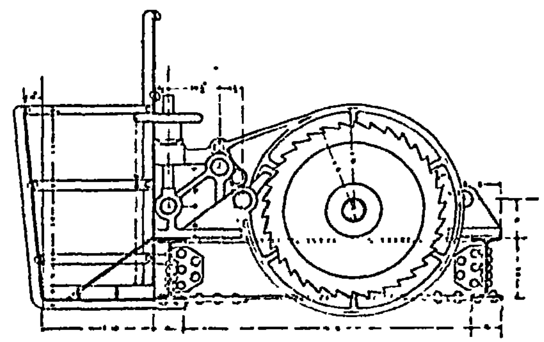


FOURACRES' DOUBLE TUMBLER SHUTTER.

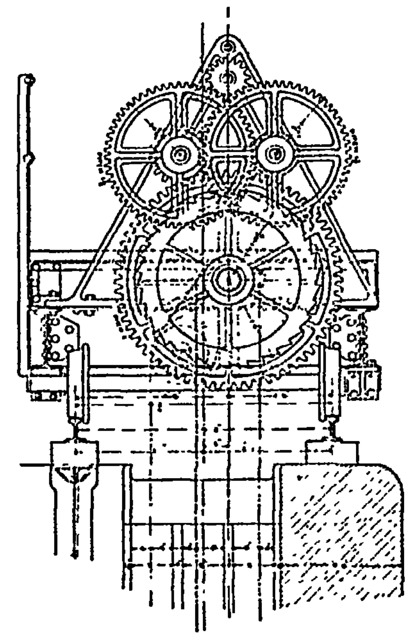
This form of movable dam has been adopted on the crest of the Sone weir in the part where the centre sluices originally existed, but which have now been built up. (See page 152.)

In the United Provinces and the Punjab nearly all the under-sluices on the river weirs are fitted with draw-gates which are raised by a traveller running on rails laid above high-water level on the tops of the piers (see Plates opposite page 190, and on pages 192 and 193). The vents are generally 20 feet in the clear; the gates run in cast-iron grooves in the piers, which, in most cases, are carefully planed and very accurately fitted. There are usually two gates in each vent, one above the other, but running in separate grooves; they are made of wrought iron, and vary in height according to the necessities of the case. Thus in the Myapore under-sluices of the Ganges Canal there are two gates, each 6 feet in height; on the Ravi weir of the Bari Doab Canal, both gates are 4 feet in height; on the Sirhind Canal weir at Rupar, both gates were originally 5 feet in height, but the upper one has now been increased to 7½ feet, because the water level has been raised by the falling shutters which have been placed on the crest of the weir.

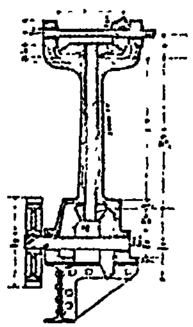
[1] M. Chanoine's system is described in Paper No. 1655, "Proceedings of the Institution of Civil Engineers," and in No. 1*a*, vol. vii., "Roorkee Professional Papers."



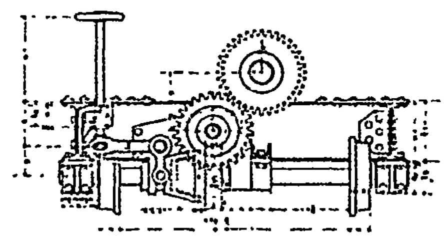
—ARRANGEMENT OF BRAKE AND RATCHET GEAR—



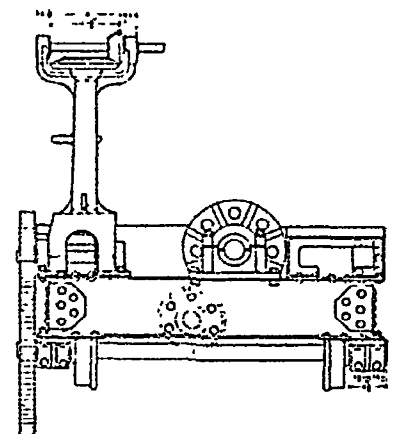
SECTION SHOWING A FRAME & DIAGRAM OF WINCH GEARING



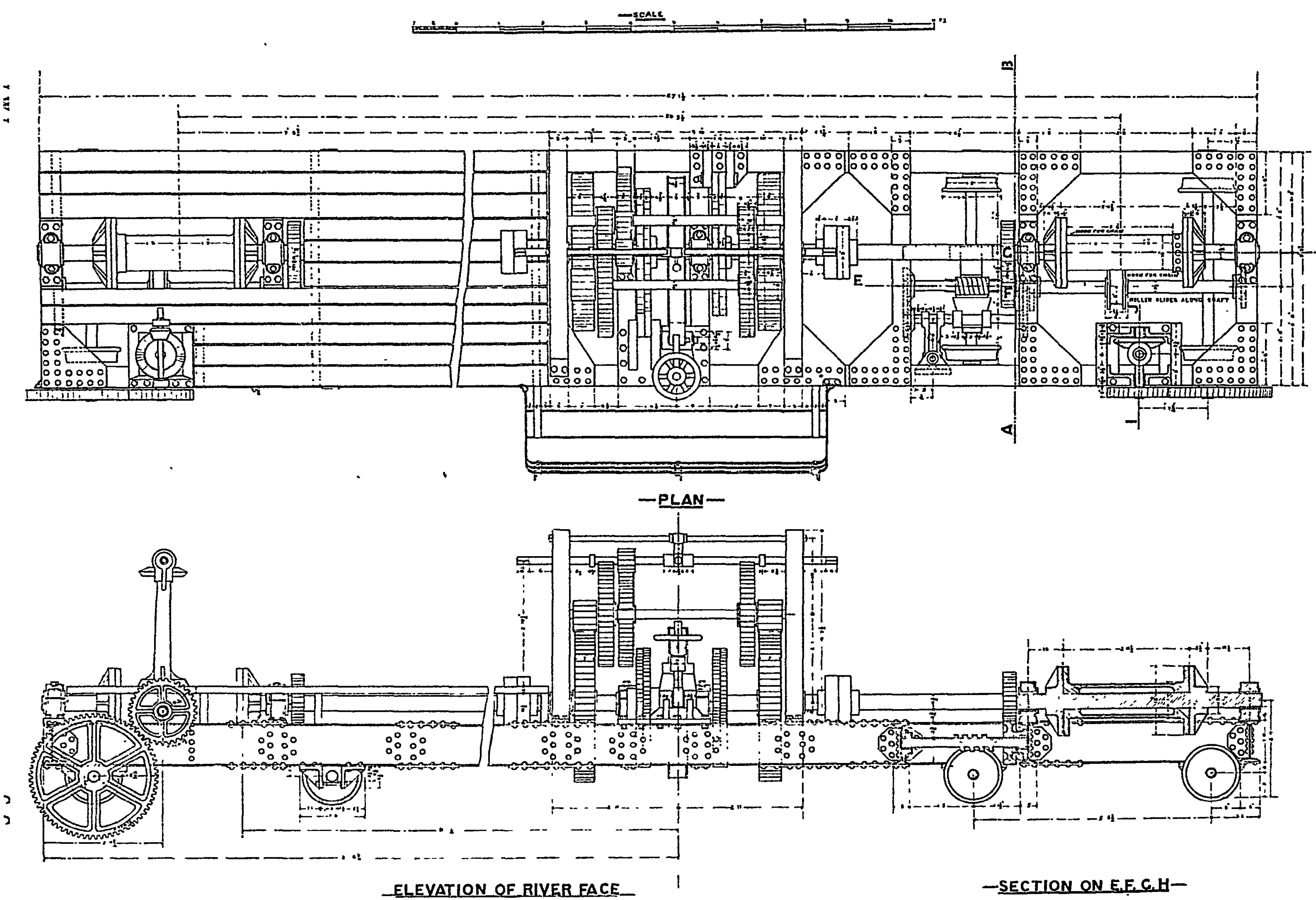
—SECTION ON I. J.—



—SECTION ON A.B.—



—END ELEVATION—



TRAVELLING WINCH ON THE CHENAB WEIR.

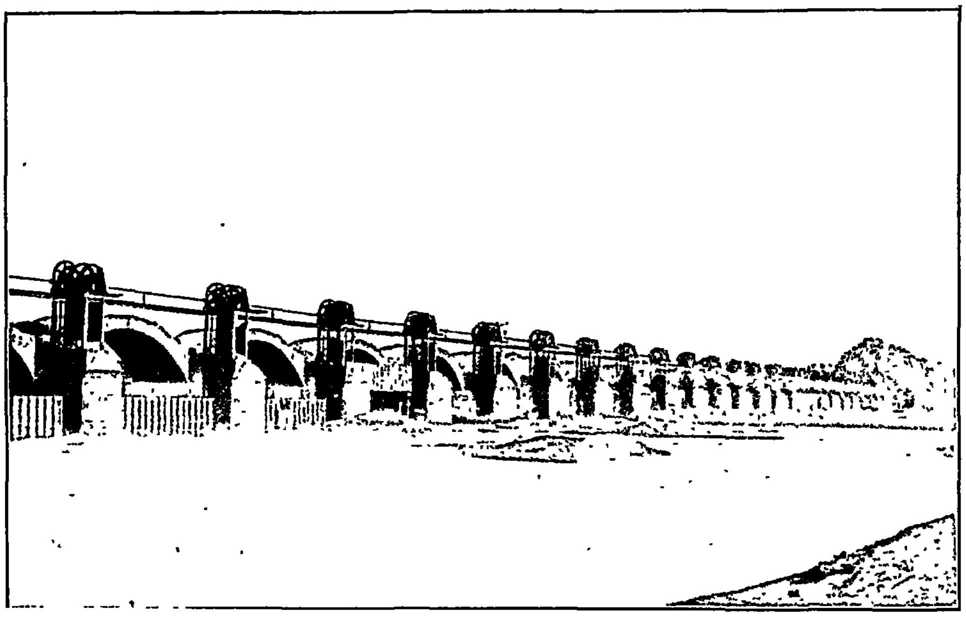
The shutters on the Jumna Canal under-sluices are each 4 feet 3 inches in height. In all these cases the design is very similar to the under-sluice gates of the Chenab Canal, which are illustrated in the Plate facing page 190, but in that case there are three gates instead of two. The gates overlap each other, when they are down in place, about 3 inches, so that they can, when necessary, be made quite water-tight by caulking the interval between them with a pole bound round with straw, which is dropped on to the top of the lower gate. These gates are lifted by chains hooked to the shackle at either end of the gate by the travellers (Plates on pages 192 and 193), which can be run over each gate in turn on the rails which are laid over the sluices. There are two travellers on the Chenab under-sluices; these can lift all the gates in seven hours, including the time required for housing the gates. In the case of the Chenab Canal the lifting chains are attached to the drums on each end of the traveller, but in some cases—in the Western Jumna and Sirhind Canals, for instance—there are chains permanently attached to the gates, which are hooked on the piers, and are brought into gear on the traveller when a gate has to be lifted. The traveller is fitted with a powerful brake, which is used when the gates are lowered, just to keep a slight check on the chains as the gate runs down in the groove, or, it may be, to lower the gate gradually if it is not necessary to drop it quickly in order to force it down into place against a strong stream. The gates, it will be noticed, are fitted with rollers, so that the friction is greatly reduced when they are dropped against a head of water. In some cases these gates, when they have been fitted without rollers, have been found to stick when they were lowered against a heavy stream, and, on the Ganges Canal, an arrangement somewhat similar to that used on the head-sluices of the Sone Canals (see page 206) was introduced by which the gates could be pushed down by a pole actuated by the traveller. In that case, however, it was not found necessary to use this arrangement, as the gates were fitted with rollers and worked quite easily.

This system of draw-gates for under-sluices has the objection that it is slow, and may be dangerous in those cases where floods rise rapidly. In the case of double gates, such as those on the Sirhind Canal, it takes about five minutes to lift and fix the upper gate in place, and ten minutes to do the same for the lower gate, even when the traveller has not to be shifted. The systems of under-sluice gates which are employed on the Orissa and Sone Canals in Bengal, which have been described in this chapter, are much quicker in their action, but much more troublesome to work.

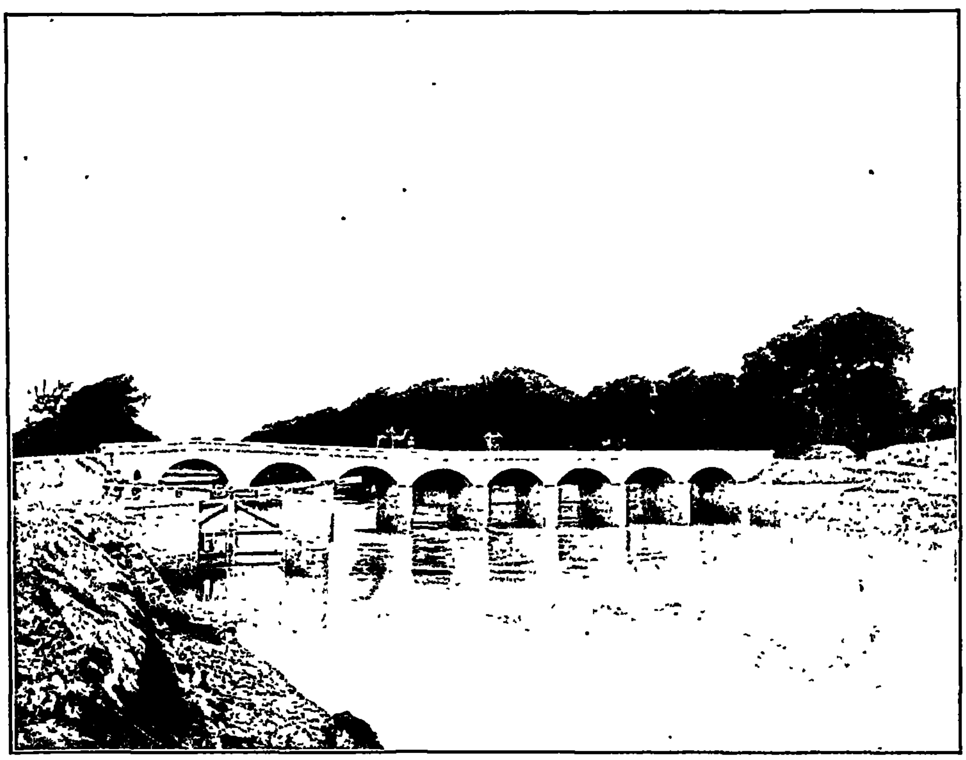
The system of draw-gates illustrated in the Plates opposite page 190 and on pages 192 and 193 has been adopted, with some modifications, on the Delta Barrage across the Nile below Cairo, and on the Assiut and Zifta Barrages also.

In Madras a system known as "Smart's" shutters has been often used. These shutters, like those just described, are broad and shallow, but, in Madras, they are heavily counter-balanced, and the gates are fitted with rollers which run[1] on discs strung on the roller axles. The illustration opposite this page shows a weir (the Coleroon Weir) which is fitted with these shutters. The counter-weight is hung by a chain which runs in a chain wheel. Great power is applied, at slow speed, through this wheel to lift the counter-balance, and the gate descends by its own weight. The gates do not really depend on the reduction of friction due to the rollers, for these, in practice, frequently become clogged with mud and dust and do not revolve. "Smart's" shutters have been erected in all sizes in Madras up to 40 feet by 12 feet. They are admitted to be inferior in design to "Stoney's" shutters, and the principle of the latter shutters is now being adopted in Madras. The sketch on page 195 shows, in outline, the design for the proposed regulator across the Penner River, with shutters 80 feet broad and

[1] Note by Mr. A. T. Mackenzie, dated Aug. 1st, 1904.



Counter-Balance Lift Gates, Coleroon Weir.

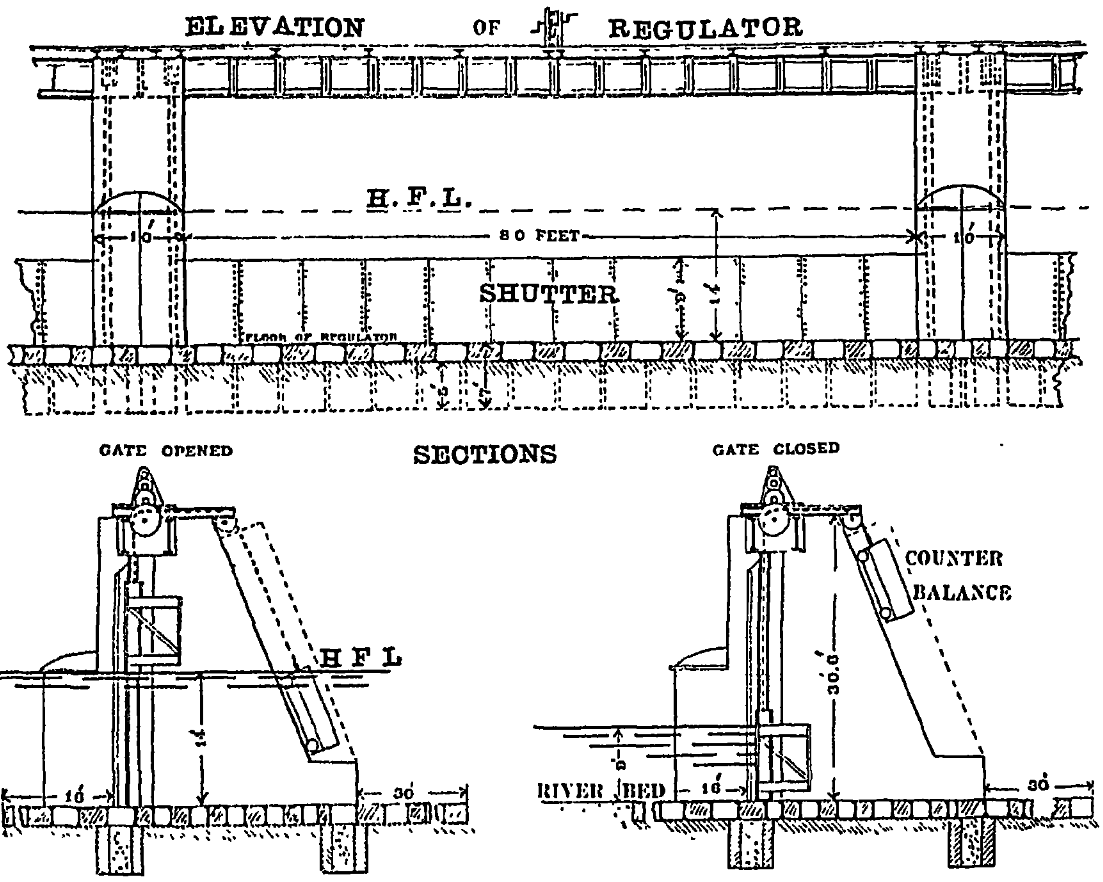


A Needle Regulator on the Fuleli Canal in Sind.

[*To face page* 194.

9 feet deep. The shutters are counter-balanced on the piers, and will run in the grooves on "Stoney's" rollers, which really do remove the friction very greatly.

In the large masonry dam of the Bhatgarh Reservoir in the Bombay Presidency there are fifteen vents, or under-sluices (as they are called), which have been constructed with the object of preventing the deposit of silt in the reservoir (see page 86). Each of these vents[1] is 8 feet high and 4 feet wide in the clear, and they are subjected to a head of over 80 feet when the reservoir is filled to the highest flood level. Each cast-iron gate with its steel lifting-rod 4½ inches in diameter, weighs about 4½ tons. The top 11 feet 4 inches of the rod is screwed, and on it fits a gun-metal nut and collar, which fits in a cast-iron thrust-box, bolted to the masonry at the top of the dam. A cast-iron capstan-head fits the nut, and is worked by six



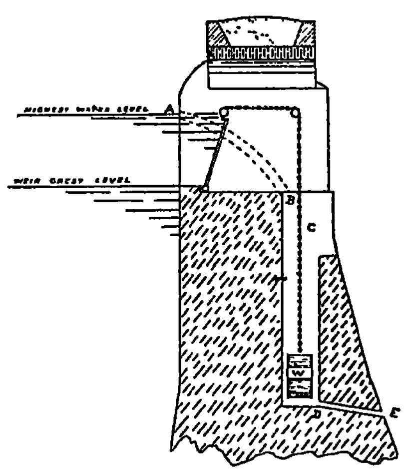
PROPOSED REGULATOR GATES, PENNER RIVER, MADRAS

wrought-iron arms. The screen in front of each gate consists of wrought-iron double-headed rails, 2½ feet from the face of the sluice, weighing 66 lbs. to the yard, fixed in horizontal rows 1 foot apart, the ends resting in grooves in the masonry piers, and kept in position by vertical bars 1¼ inches in diameter. The calculated maximum velocity through the sluices is 60 feet a second. One defect to be noted in the design is the position of the cage of rails with respect to the sluice. It should have been at least 12 feet in front instead of only 2½ feet.

The waste weirs of large reservoirs are necessarily constructed with a crest level which is below the maximum or flood-water level in the reservoir, while the main dam, which forms the

[1] This description is taken from page 18 of the "Report on the Nira Canal Project," published by the Government of Bombay in 1892.

reservoir, is constructed to retain the water up to that maximum flood level. If the waste weir is an open one, that is, if there are no shutters, or planks, or needles on its crest, the maximum level of the water impounded in the reservoir is necessarily the level of the waste weir crest, and not the higher level which the main dam is capable of sustaining, so that the full quantity of water which the works are capable of impounding is not stored, for the level of the surface, after a flood has passed, falls to the crest of the waste weir. In many cases waste weirs are fitted with planks or needles, so that the ventage of the weir can be closed after the flood season, but when there is still some discharge from the catchment, and the water surface is thus raised up to the full level which the main dam can sustain; but this plan is a dangerous one, especially in those cases where sudden floods occasionally occur after the monsoon season has passed, for in that case it may not be possible to remove the planks or needles in time, and the result may be disastrous. In many cases it has been the custom to cut the waste weir to different levels in parts, and to close these parts one by one with low earthen embankments, which, in the event of a sudden flood, would cut away rapidly by the action of the water as soon as they were topped by the stream. But this method is, at the best, an unsatisfactory one, partly because it is uncertain in its action, but mainly because it is a lengthy business to remake the embankment after a sudden flood has destroyed it, and it may be impossible to do it in time to refill the reservoir to the full level. Experience in the larger reservoirs in Bombay[1] has shown that, to ensure the full additional storage above the level of the waste weir crest, a method which is entirely automatic both as to opening and closing is essential. One solution of the problem of an automatic gate for waste weirs was found by Mr. Whiting, who designed a self-opening gate, which will be understood from the sketch in the margin:—



WHITING'S SELF-ACTING WASTE WEIR GATE.

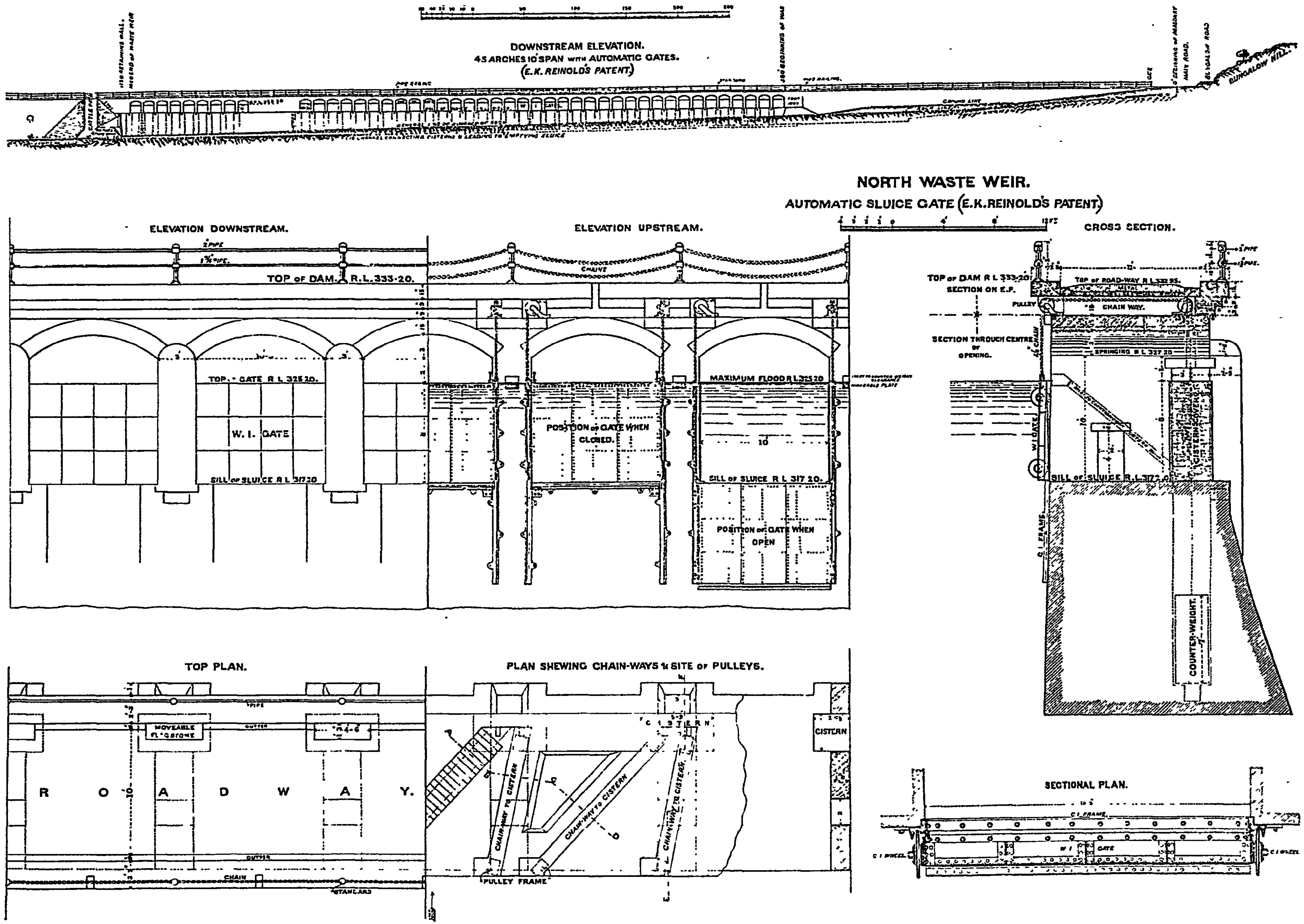
The gate was hinged at its lower edge to the crest of the waste weir, and was capable of falling down-stream flat on the crest. It was retained in place by the chain and counter-weight W so long as the water was below the maximum flood level. The counter-weight hung in a chamber C D, which had a small outlet pipe D E at the bottom, and a large inlet pipe A B (led through the pier) at the top. When the water had risen to such a height in the reservoir that the inflow into the chamber through A B was greater than the outflow from D E, the chamber filled and the counter-balance W lost weight sufficiently to allow it to rise; when the level in the reservoir was so reduced that the water flowing into the chamber through A B was less than that discharged through the pipe D E, the chamber emptied itself and the gate would rise as soon as the weight of the water flowing over it would permit the counter-balance to raise it. The principal objection to this gate was that it would not lift until the water had fallen to about 2 feet above the waste weir crest level, and the storage of a considerable depth of water was therefore lost. A gate which was more tender in its action was found to be necessary, and the design which is shown in the plate facing this page was worked out by Mr. Reinold.

This form of gate, which has been erected on the Bhatgarh Dam of Lake Whiting, near Poona, is very suitable where there is a clear overfall from the sill of the sluice, but it cannot be adopted in ordinary river weirs. The gate, which is of iron, is suspended by chains running over pulleys above it; there are two chains to each gate, both of which are attached to a single

[1] Memorandum on Waste Weir Shutters in the "Report on the Nira Canal Project," Bombay, 1892.

NORTH WASTE WEIR.

AUTOMATIC SLUICE GATE (E.K.REINOLD'S PATENT.)



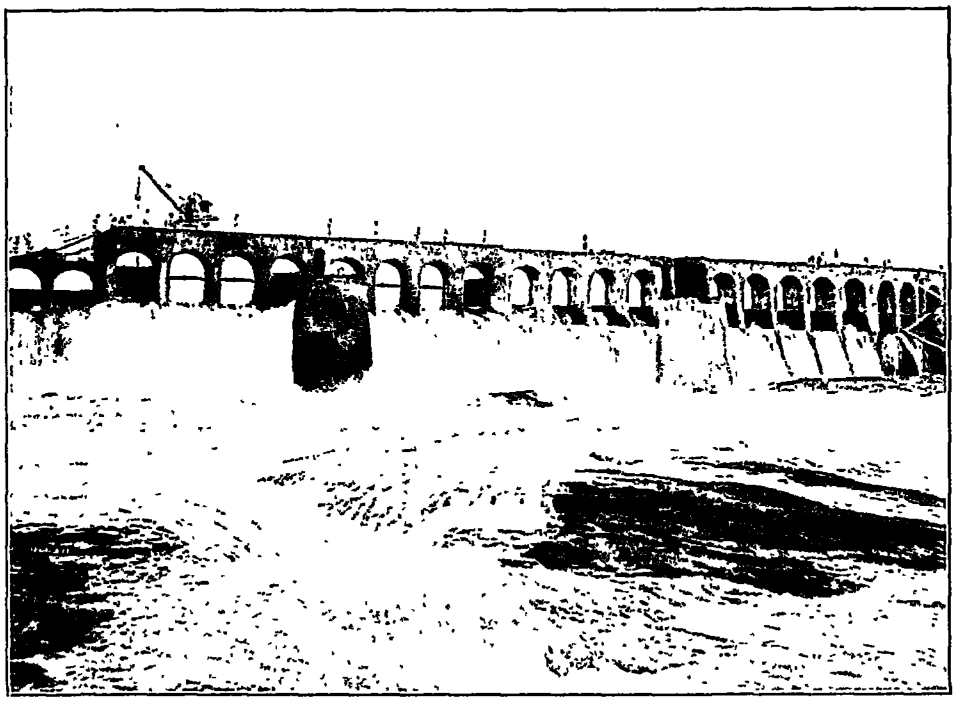
counter-balance weight working in a chamber at the back of the sluice. This chamber has an outlet pipe at the bottom which discharges at the back of the weir, and an inlet pipe at the top which is supplied from the full supply level of the reservoir. The discharge of the outlet pipe is less than that of the inlet pipe when the water in the reservoir is at or above full supply, so that, under those circumstances, the counter-weight chamber is maintained full of water. When the water in the reservoir is below full supply level the chamber becomes empty and the counter-balance weight retains the gate at its highest point; but when the water rises to full level and flows into the chamber, the counter-balance loses weight[1] to such an extent that the excess weight of the gate over the diminished weight of the counter-balance is sufficient to overcome the small amount of friction, and the gate moves vertically downwards, and continues to do so as long as the water in the chamber rises. But when the discharge through the opened gate has so far reduced the level of the water in the reservoir that the supply entering the chamber is insufficient to keep up the level of the water in it, the counter-balance regains the weight necessary to lift the gate, and it rises up to the top of its run. It will be noticed that the gate runs on large rollers working in cast-iron grooves. The bearing surface of the gate and the seating on the cast-iron frame on the piers are tapered so that there is no sliding friction when the gate falls; it recedes from the seating immediately it falls below its highest point. Set screws are provided, so that the position of the gate with reference to the seating can be accurately adjusted. Each of the gates weighs 6,328 lbs.; the counter-balance is $7\frac{1}{2}$ feet by $2\frac{3}{4}$ feet by $5\frac{1}{2}$ feet, giving a displacement of 7,051 lbs.; it is made of wrought-iron $\frac{1}{4}$ inch thick; a certain amount of sand is added, making the total weight 9,200 lbs. When the weight is free in air, the power available to draw up the gate is (9,200 − 6,328 lbs.) 2,872 lbs., and when it is immersed in water its effective weight is reduced to (9,200 − 7,051) 2,149 lbs., which is 4,179 lbs. less than the weight of the gate. The weights can be adjusted to provide exactly equal power both for opening and closing the gate, by making the counter-balance equal in weight to the entire weight of the gate, plus half the weight of its own displacement; but it is desirable that the force to open the gate should be the greatest, for no disaster could occur from any hitch in closing it, but it might if it did not open readily. As a matter of fact, experiments have shown that the gates work excellently with the weights given above. The leakage is said to be very small.

The waste weir on Lake Fife, near Poona, has a discharging capacity of nearly 75,000 cubic feet per second, the maximum calculated flood being 62,000 cubic feet, or $\frac{1}{2}$ inch per hour over the whole catchment of the lake. The waste weir has been subjected to several changes. It has always been intended to store a portion of the supply in the reservoir above the level of the sill of the waste weir, and various expedients—all more or less unsatisfactory—have been adopted.[2] In 1884 arrangements were made for storing a depth of 4 feet above the sill by means of a movable weir of teak planks fixed in iron standards. This proved dangerous on more than one occasion. In September, 1900, a flood rose, when the planks of the temporary weir were up, 3·65 feet above the top plank, and 1·40 feet above the safe maximum flood level. A temporary weir of boards, nearly a quarter of a mile long, cannot be readily manipulated. When the flood overtopped the boards, the men lost control of the arrangement and looked on helplessly until the flood had worked its will.

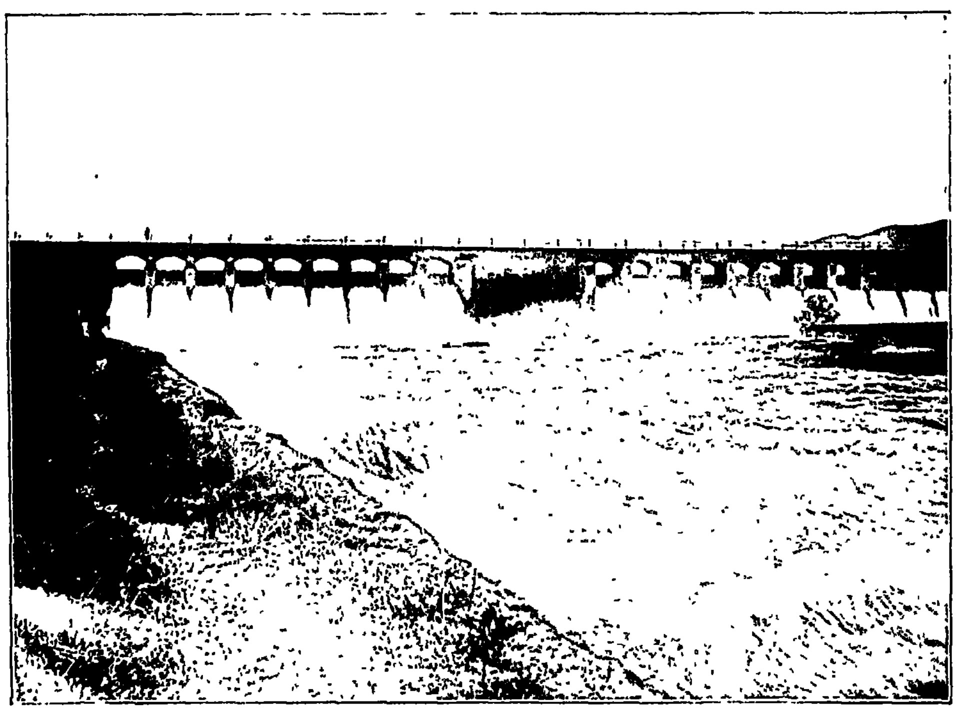
The volume which it is possible to store above the sill of the waste weir is 1,244 millions of cubic feet, or nearly half the total available storage of the lake. As this volume was essential to the irrigation, it was determined to erect efficient automatic movable shutters on the crest of

[1] This description is taken from a Note by Mr. W. H. Le Quesne, Executive Engineer, Nira Canal.

[2] Note by Mr. M. Visvesvaraya, B.A., on the Automatic Waste Weir Gates of Lake Fife.

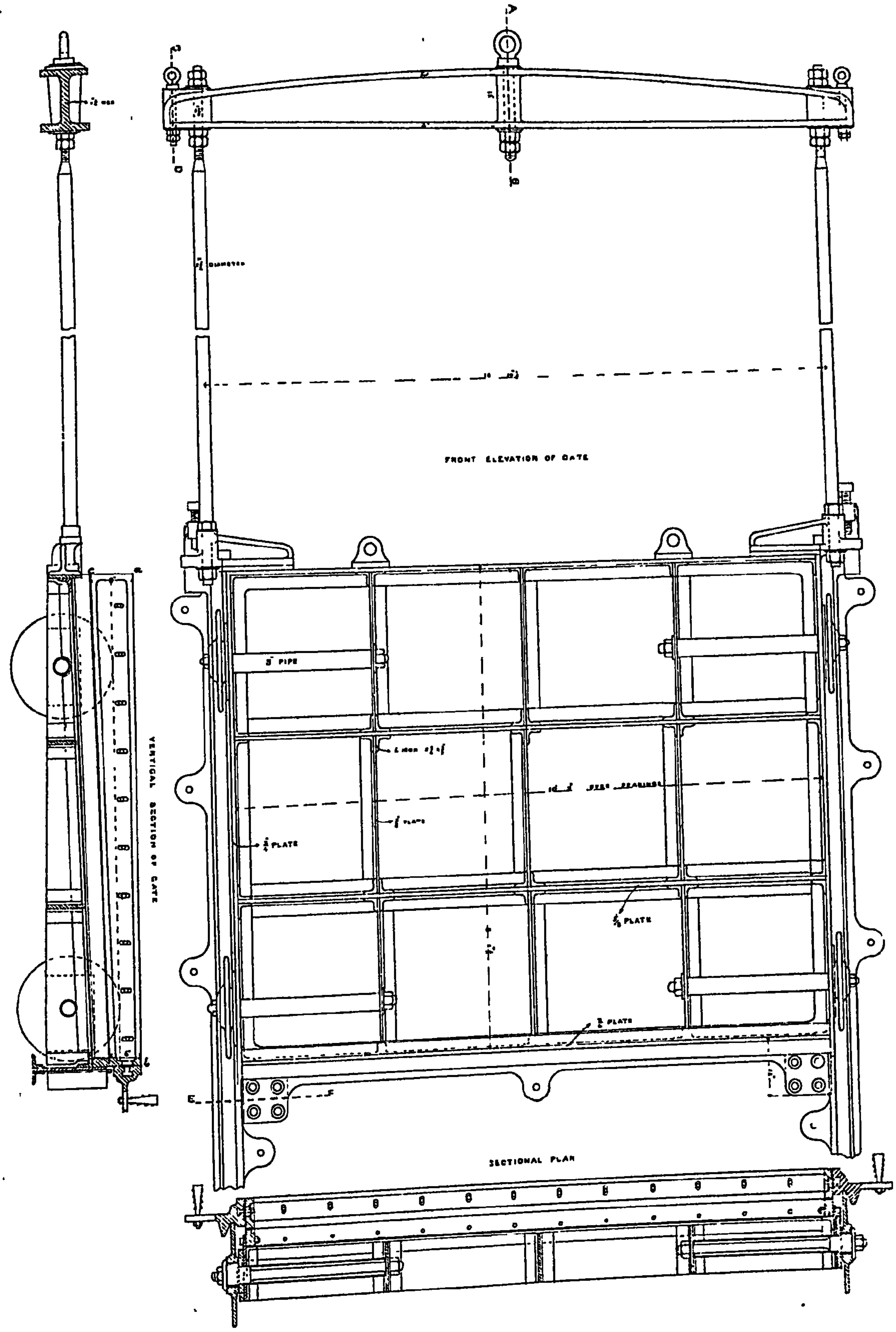


Grouped Automatic Waste-Weir Gates, Lake Fife, Bombay



Single Automatic Waste-Weir Gates, Lake Whiting, Bombay.

[*To face page* 198.



AUTOMATIC GATES ON THE WASTE WEIR OF LAKE FIFE.

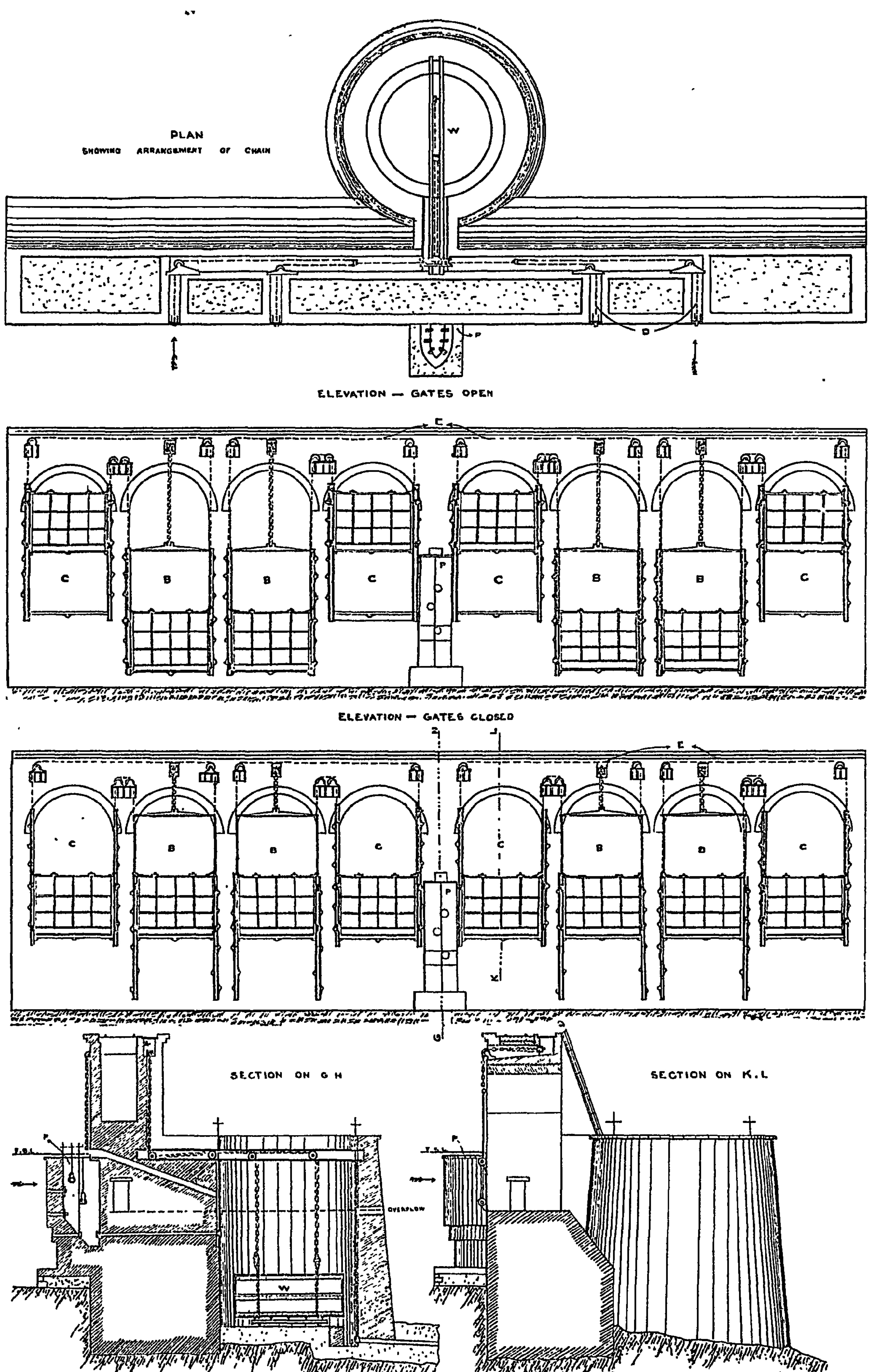
the waste weir. The automatic gates of the Bhatgarh pattern, which have just been described, were considered unsuitable for several reasons, and it was decided to erect a series of eighty-eight gates on designs which were prepared by Mr. Visvesvaraya. The gates are in sets of eight, and one counter-weight regulates each set. Each gate covers a clear opening 10 feet wide and 8 feet high. Eleven sets of these gates have been constructed over a length of 1,200 feet of weir. The gates themselves are similar to those on the Bhatgarh waste weir. The gates move on rollers running on the sluice frame: the bearing surfaces of the sluice frame and gate are tapered in opposite directions, so that when the gate is closed and the surfaces come in contact the joint is water-tight. There are two systems. In the first system the gates are partially balanced one against the other: four of the gates descend and the other four ascend when the set of eight gates are opened. In the other system, which may be more suitable in certain cases, all the set of gates rise when they are opened, and an intermediate balance weight is introduced.

The first system is illustrated in the Plate on the next page. The gates, on the weir face, work in pairs. They are suspended from pulleys and the heavier gate of the pair weighs from 100 to 120 cwts. and the lighter one about 44 cwts. The sluices open when the heavier gate of the pair is allowed to fall. When fully open the heavier gate lies below the sill of the weir and the lighter one is above the flood-water level. The gates are closed by the action of a counter-weight which is attached, by a chain or wire rope, to the heavier gate: when the heavier gate is lifted the lighter one descends by its own weight. The counter-weight works in a cistern constructed below the waste weir. It is formed of a water-tight cylinder with a cubic capacity of 760 to 800 cubic feet. But the diameter and height varies with the depth of overfall and nature of the site. The cylinder is filled with sand to the requisite extent.

The action of the counter-weight will be understood by a reference to the Plate on the next page. An inlet channel, made in the pier with its mouth at P, leads from the reservoir into the counter-weight cistern. The sill at P is about 6 inches below the level of full supply. An outlet pipe is laid, from the bottom of the cistern, and taken to the nearest point, beyond the waste weir channel, where it can discharge freely into air at all times. This outlet pipe is throttled by a sluice valve, and this is so regulated that the flow from the outlet pipe is always less than the maximum flow into the cistern through the inlet pipe. When the water rises to the full supply level in the reservoir it begins to flow, at P, into the cistern through the inlet, and the water gradually immerses the counter-weight. As soon as sufficient water has accumulated in the cistern the counter-weight floats. The tension of the chains connected with the heavier gates is relaxed, and as the counter-weight rises the gates open, the heavier one drawing up the lighter. When the flood has passed and the water level in the reservoir falls below the mouth of the inlet channel at P, the cistern is gradually emptied through the outlet pipe. The counter-weight regains the weight it had lost by immersion, and as it falls it pulls up the heavier gate of each pair: the lighter one then descends of its own weight and the vents are closed.

There are valve chambers provided in front of the waste weir, with sluice valves in them at various levels. By the manipulation of these valves the water can be maintained in the lake at any desired height above the sill of the waste weir.

The total works cost of the installation of eleven sets of gates was about 5 lakhs of rupees; the eighty-eight gates themselves, with all iron work connected with them, cost about 3 lakhs. Each set of eight gates takes about seven minutes to open and about eight minutes to close when the valves are worked by hand. The sluices of all the eleven sets can be opened or closed by one man in about twenty minutes: in that time a flood 8 feet deep and nearly a quarter of a mile wide is released or retained by the sluices.



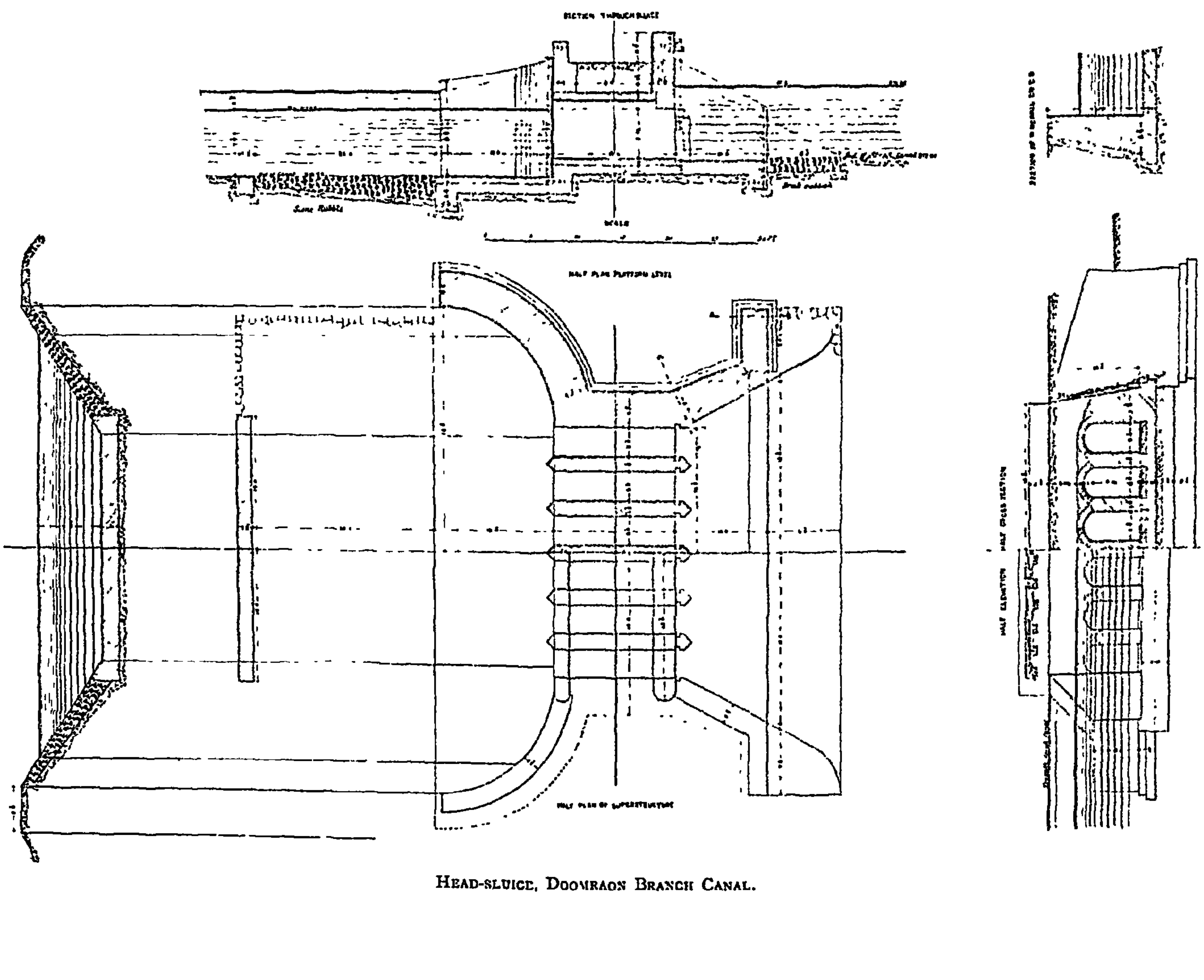
ONE GROUP OF AUTOMATIC GATES ON THE WASTE WEIR OF LAKE FIFE.

CHAPTER XII.

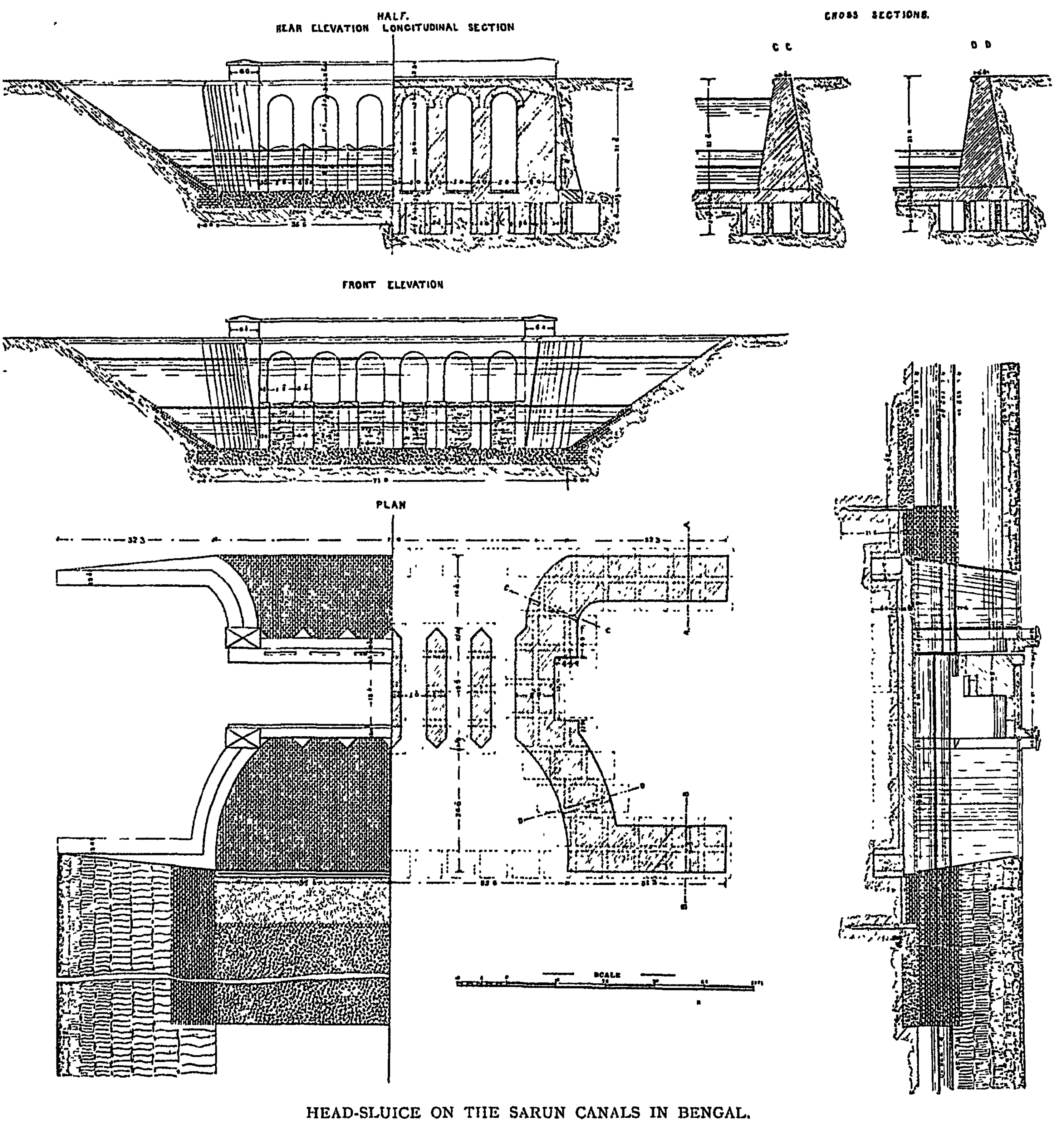
REGULATORS, HEAD-SLUICES, ESCAPES, CANAL FALLS, WEIRS, BRIDGES.

Head-sluices or Regulators—Head-sluices liable to be "Blown up"—Head-sluice Shutters—Head Regulator, Chenab Canal—Head Regulator, Trebeni Canal—Regulators—Regulation by Needles—The Egyptian System of "Verticals" (or Needles) and "*Horizontals*"—*Escapes*—*Egyptian Escapes*—*Pooling below Escapes, and Methods for Preventing it*—*Qushesha* Escape, carrying 80,000 cubic feet a second—Canal Falls or Weirs—Grating and "Ogee" Falls—Rapids on the Bari Doab Canal—The Cascade Rapid—Canal Falls in Southern India—Impounded Water in Canal Reaches—Notch Falls on the Sirhind Canal—Best form for Notches—Canal Bridges.

THE masonry work at the point where a canal takes off from a river is called the head-sluice or regulating bridge; its object is to control the supply entering the canal. Two typical examples of these works are given in the Plates on this page and on page 203, which show



HEAD-SLUICE, DOOMRAON BRANCH CANAL.



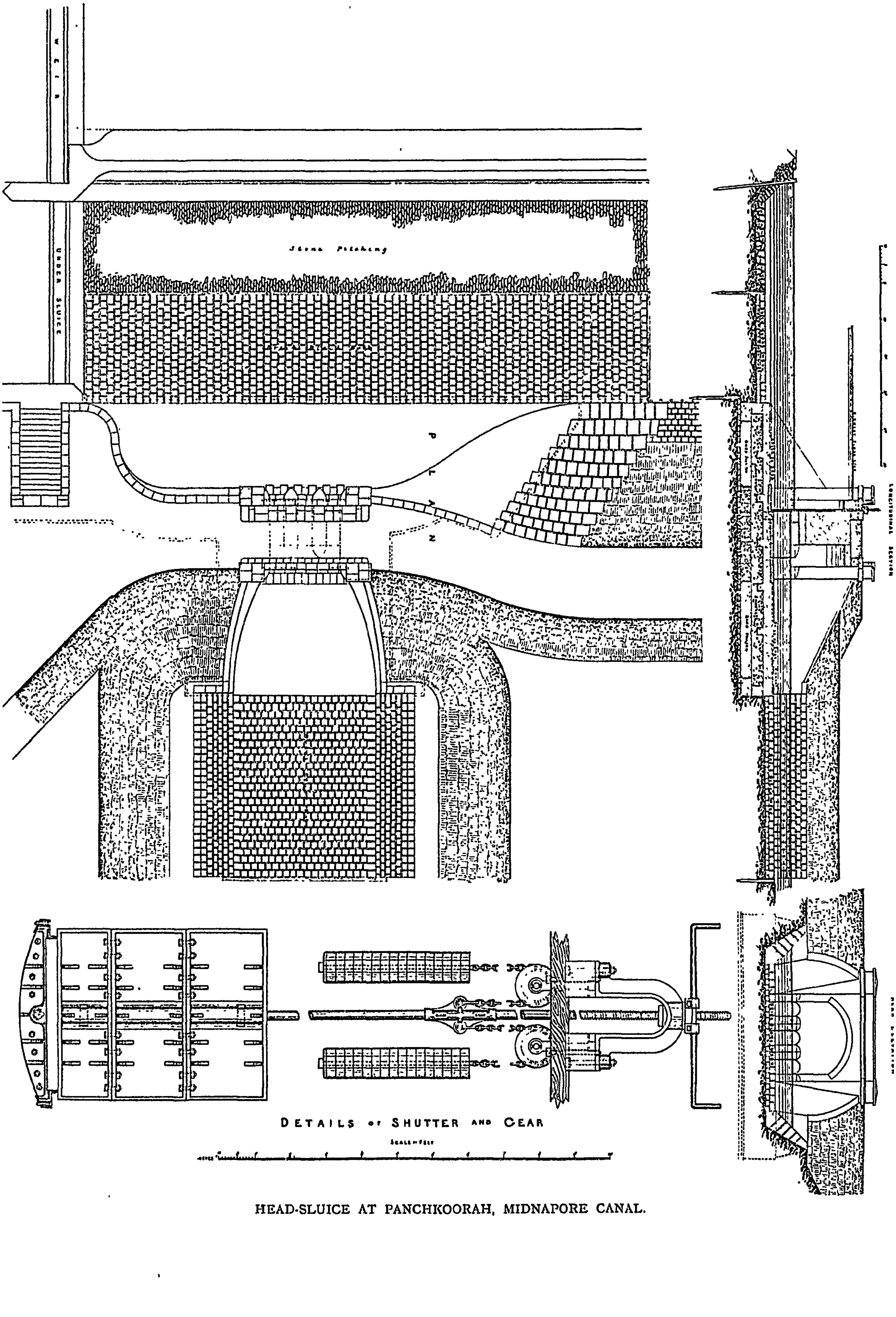
HEAD-SLUICE ON THE SARUN CANALS IN BENGAL.

head-sluices on the Sone and Sarun Canals in Bengal. Other examples will be found in the Plates on pages 18, 165, 205 and 209. There are on most canals other regulators at various points of the system—most frequently in connection with escapes—which control the discharge of the main branches; a good example of one of these is given in the Plate on page 211. The head-sluices of minor channels are often similar in design to the one at the off-take of the main canal from the river, but the latter must necessarily be higher and stronger, as it has to be carried above the high flood level of the river. There are very few (if any) perennial canals in India which have open heads without any sluice; but it has already been pointed out that the inundation canals of the Punjab, Sind, and Egypt (pages 27 and 48) have no head-sluices, but are in most cases provided with regulators at various points.

The *dimensions* of a head-sluice on a river bank are primarily determined by the discharge which has to be passed through it, with the head which is available, according to the levels of the river and the canal at the different seasons. It is generally a good plan to allow ample ventage in head-sluices at the off-take: a few extra vents add very little to the cost, and may often be very valuable when the supply in the river is low, and, in cases where difficulties with silt are probable, a head-sluice should be designed to take the full supply from the surface in a film not more than 2 feet in depth (see Chapter III.). The floor of a river head-sluice should generally be at least as solid as that of the under-sluices, for, although it has not to withstand the great velocity and heavy rolling friction of the flood, it is more liable to be "blown up" by pressure from below. An under-sluice is subjected to the greatest strain, in this respect, when the water in the pool above the weir is level with the weir crest, but the head-sluice has to bear the difference in level between the high flood of the river and the ordinary canal surface, which is often greater than that brought upon the under-sluice. Several head-sluices in Bengal have been wrecked by the floors being "blown up." One case was that of the head-sluice at Panchkoorah (Plate, page 205), on the Midnapore Canal. General Rundall writes of this sluice as follows[1]:—"The work in question is situated at the head of a bend of a canal supplied from a branch of the river Cossye, and, having to supply an area of only 20,000 acres, it is a small work, that is, it has only two vents; but the rise and fall of the river being great, the sluice itself was obliged to be built high. The difference of level between the surface of the river in full flood and the water in the canal is 18 feet. After having been in use for three or four years during which interval one high flood had occurred, on the occurrence of another similar flood it suddenly, without any warning, blew up, the only assignable reason for the catastrophe being that the water from the river must have been forced under the upper curtain wall, and that the flooring was not able to bear the great pressure that was thus brought upon it. On rebuilding the work, the dimensions were therefore increased, principally those of the flooring; the curtain walls, which before were 6 feet deep below the floor, were increased to 10 feet, and further protected by a row of piles sunk 15 feet below the foundations. The width of the floor was made 80 feet, and its thickness increased from 4 to 6 feet. An apron of brick blocks projects 50 feet beyond the floor on the canal side, and 30 feet on the river face. The velocity due to a head of 18 feet is about 30 feet per second; hence, though this work is but small compared with those constructed on the larger canals, yet it exhibits a good example of what works of this description are exposed to, and the precautions that are required under similar conditions. Being situated in the region of alluvial soil nearly 30 miles distant from any stone quarries, with only cart carriage available, it was not possible, on grounds of economy, to use stone for the mass of the work."

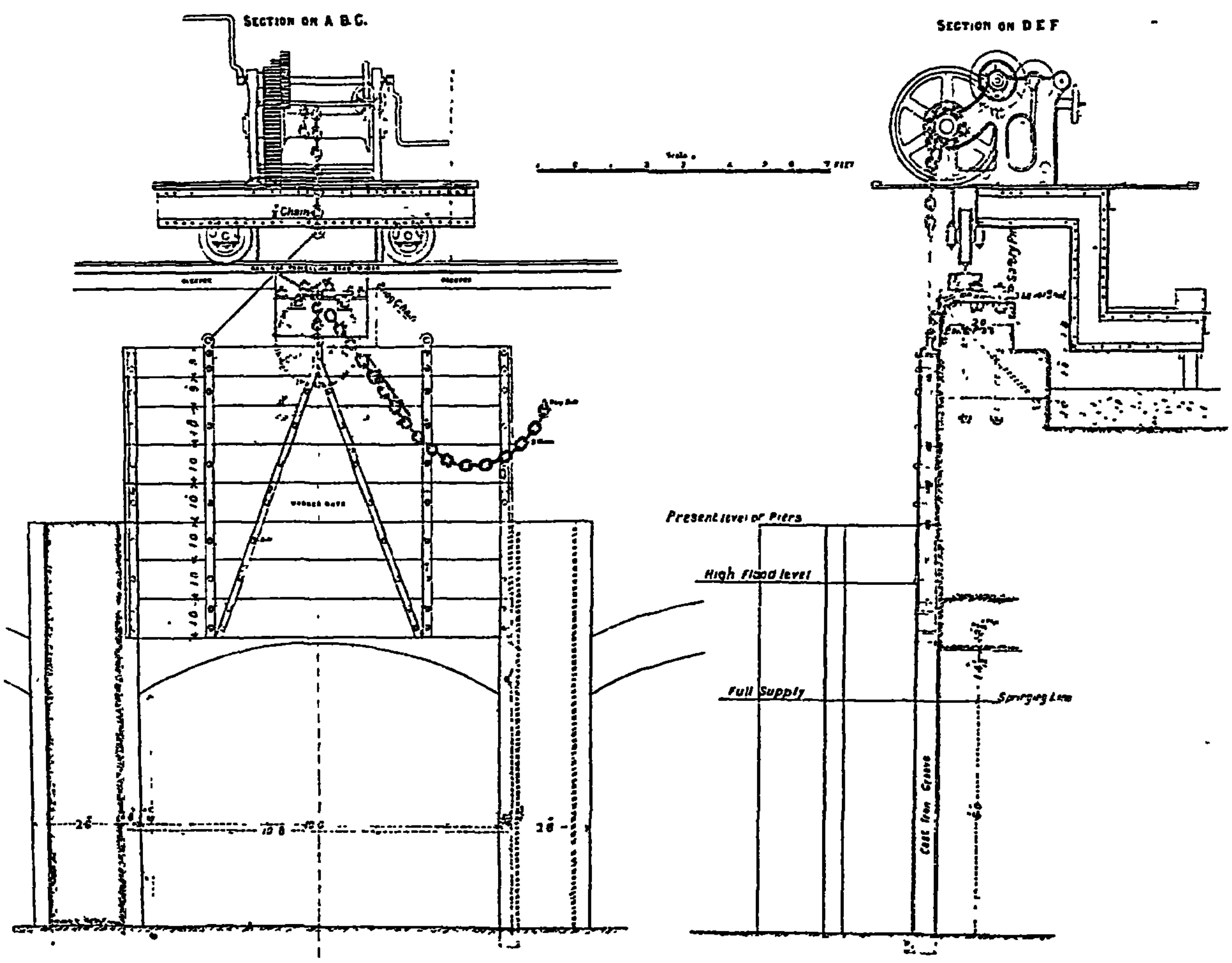
The vents of head-sluices are generally 5 or 6 feet wide only, and, as a rule, are controlled by

[1] "Irrigation Works in India," Chatham Lectures, 1876.



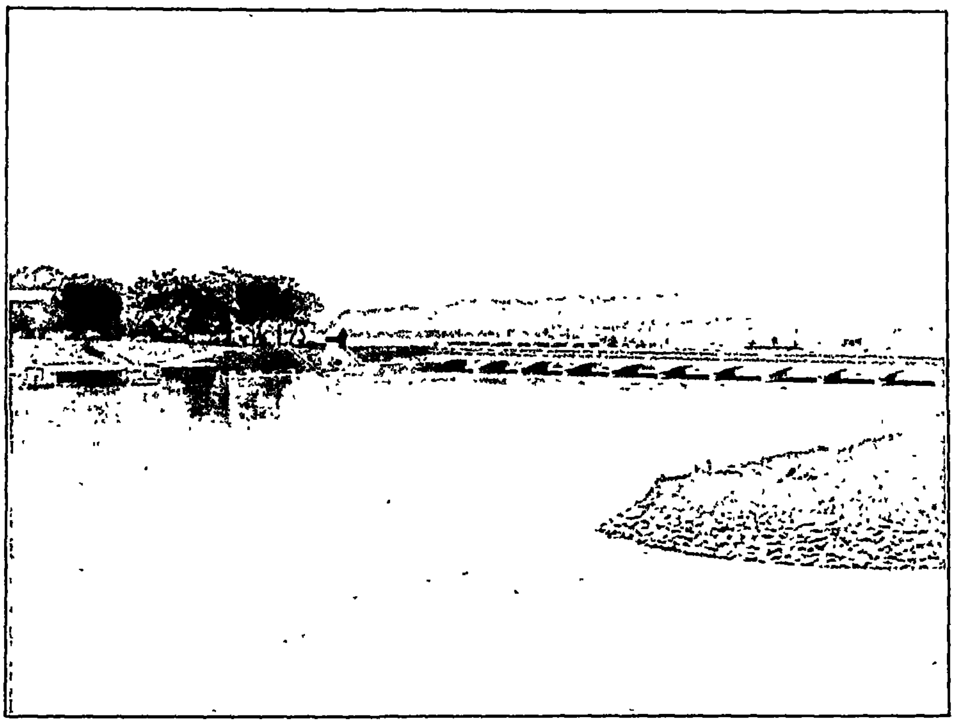
HEAD-SLUICE AT PANCHKOORAH, MIDNAPORE CANAL.

draw shutters such as those shown in the Plates on this page and on page 209. The shutters often work in plain stone grooves or even in brick ones, but in some cases, as in the Bezwada head-sluice (Plate, page 207), cast or wrought iron grooves are fixed. Friction rollers are rarely fitted to these gates. In those cases where screws are used for lifting and lowering the gates there is no difficulty in depressing them against a head, but where a travelling winch is used to lift the gates (as in the Sidhnai, Sone, and Bari Doab Canals) there is often some difficulty in getting them down. In some cases a spar is used to do this. The travelling winch which is used

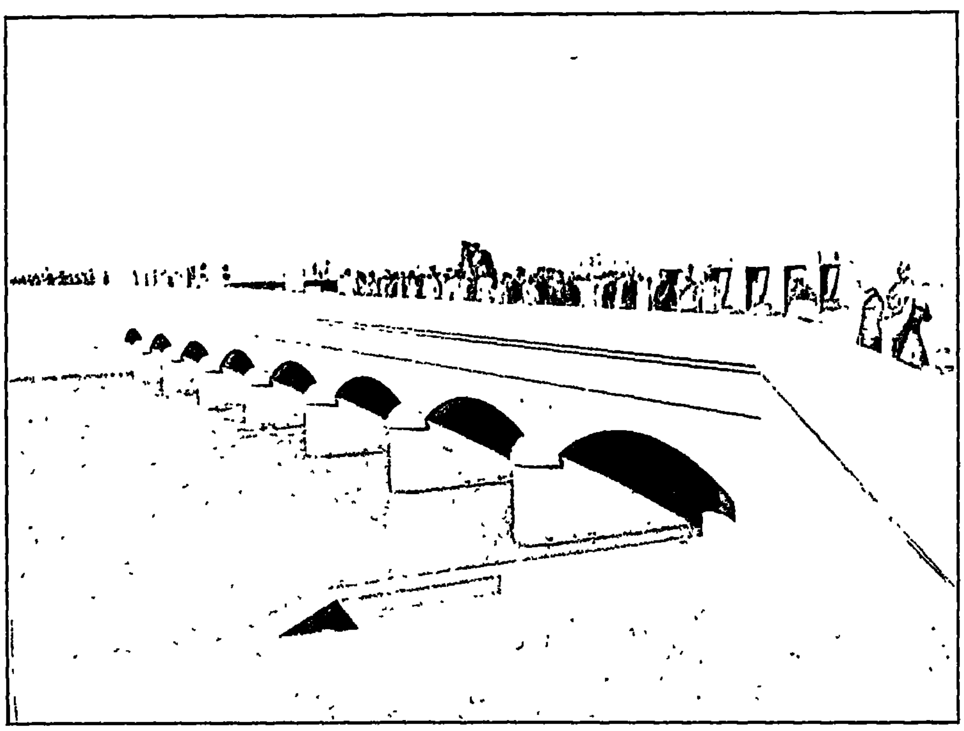


SHUTTERS OF HEAD REGULATOR, SIDHNAI CANAL.

to lift the gates is anchored to the masonry, and the spar, which rests on the top of the gate, is pressed upon it by a chain attached to its upper end, which is wound up by the winch. In several cases, as has already been mentioned, the gates of river head-sluices are divided into two or even three parts. In most cases these run in the same groove and are fished from above, when it is necessary to lift them, and hauled up by a winch; but on the head-sluice of the Kistna Canal, at Bezwada, in Madras, a more perfect but more expensive method of three separate shutters in separate grooves, each with a screw of its own, is employed (Plate, page 207). A very similar plan (page 123) has been adopted in the head-sluice of the Mandalay Canal in Burma. In the head-sluice of the Cavour Canal in Italy, double shutters of the same size, one



Head Regulator of the Sirhind Canal at Rupar



Head Regulator of the Jhelum Canal.

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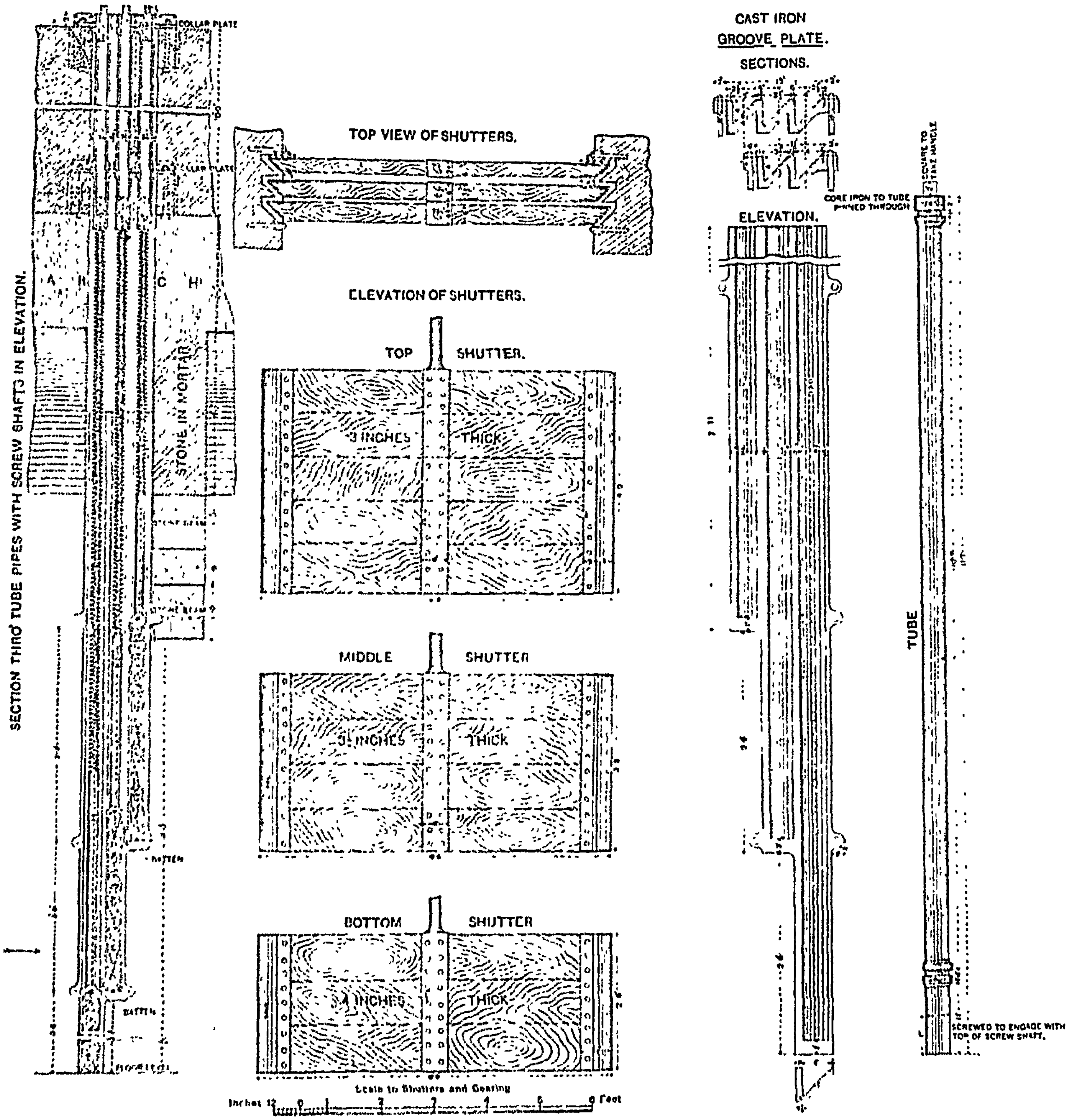
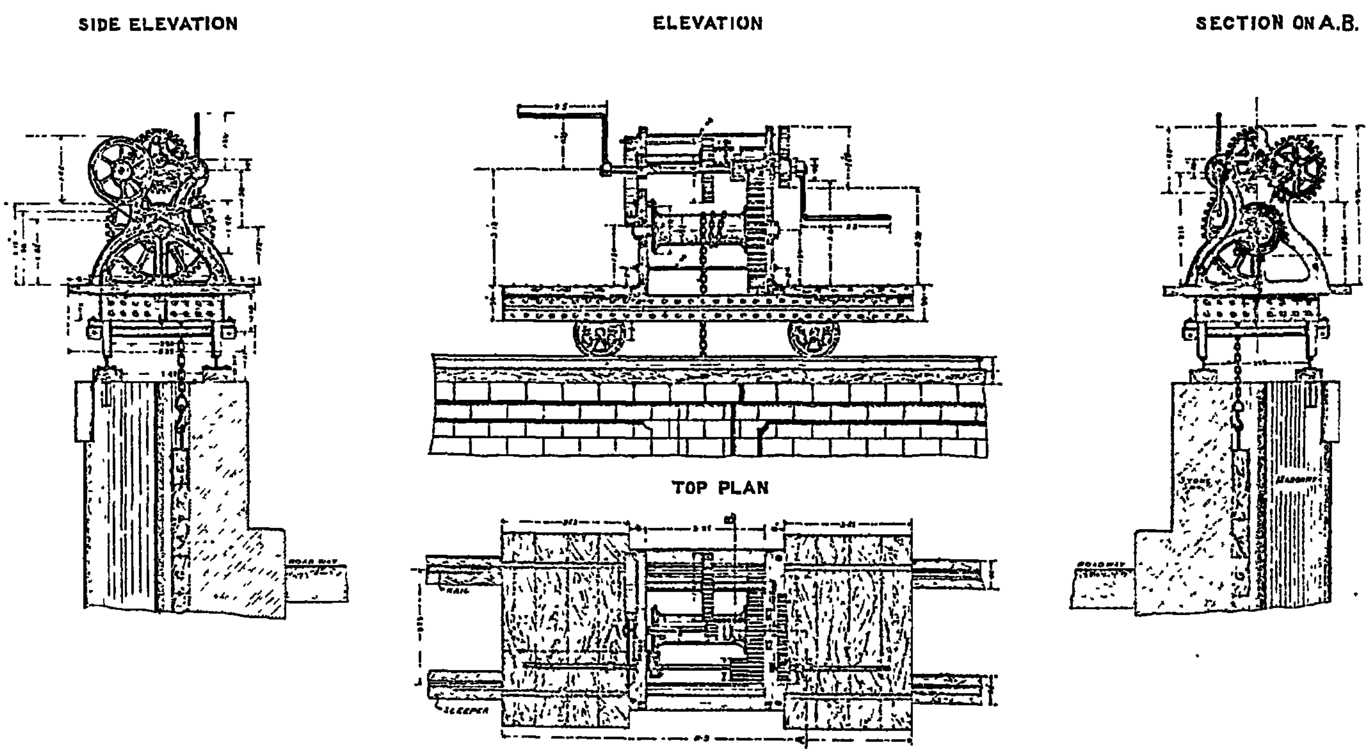


SHUTTERS OF THE BEZWADA HEAD-SLUICE, KISTNA CANALS.

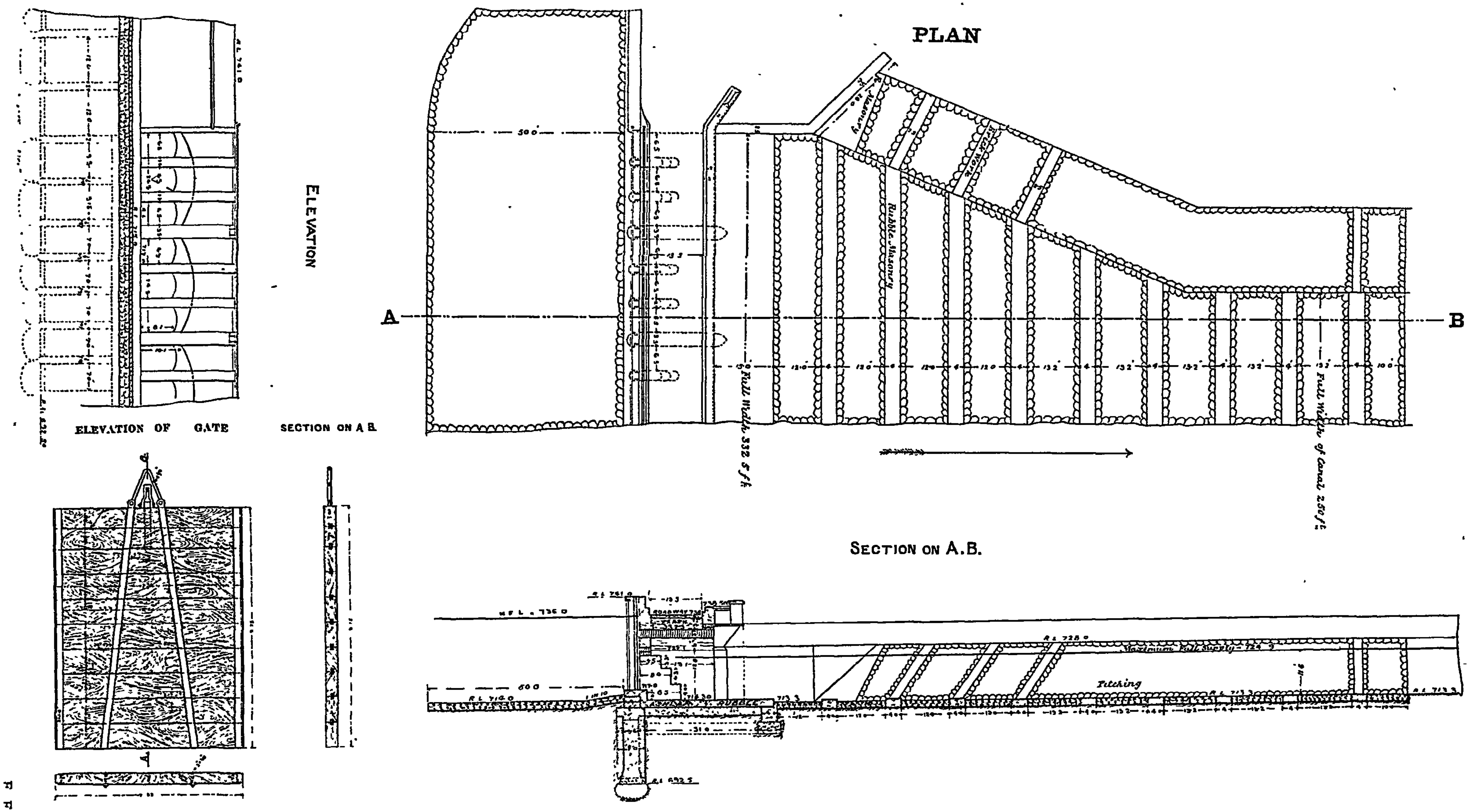
behind the other, in different grooves, are used. If one shutter, when dropped, does not close the vent, it reduces the discharge greatly: the one behind it is then dropped; it descends a little below the first one: the upper one is then raised and again allowed to run down: if this does not close the vent, the back one is again raised and dropped. These shutters are worked by a lever, and not by screws.

The head regulator of the Chenab Canal has twelve large main openings, 24·5 feet wide, as shown in the Plate on page 209. Each of these is sub-divided, by jack piers, into three openings of 6·5 feet, giving in all 294 lineal feet of waterway. The floor of the under-sluices is at R. L. 715·00, and the floor of the head regulator is R. L. 714·3. The up-stream drop wall is formed by a line of wells, which are sunk down to R. L. 692·5, which is 22 feet below the



TRAVELLER ON THE HEAD REGULATOR, CHENAB CANAL.

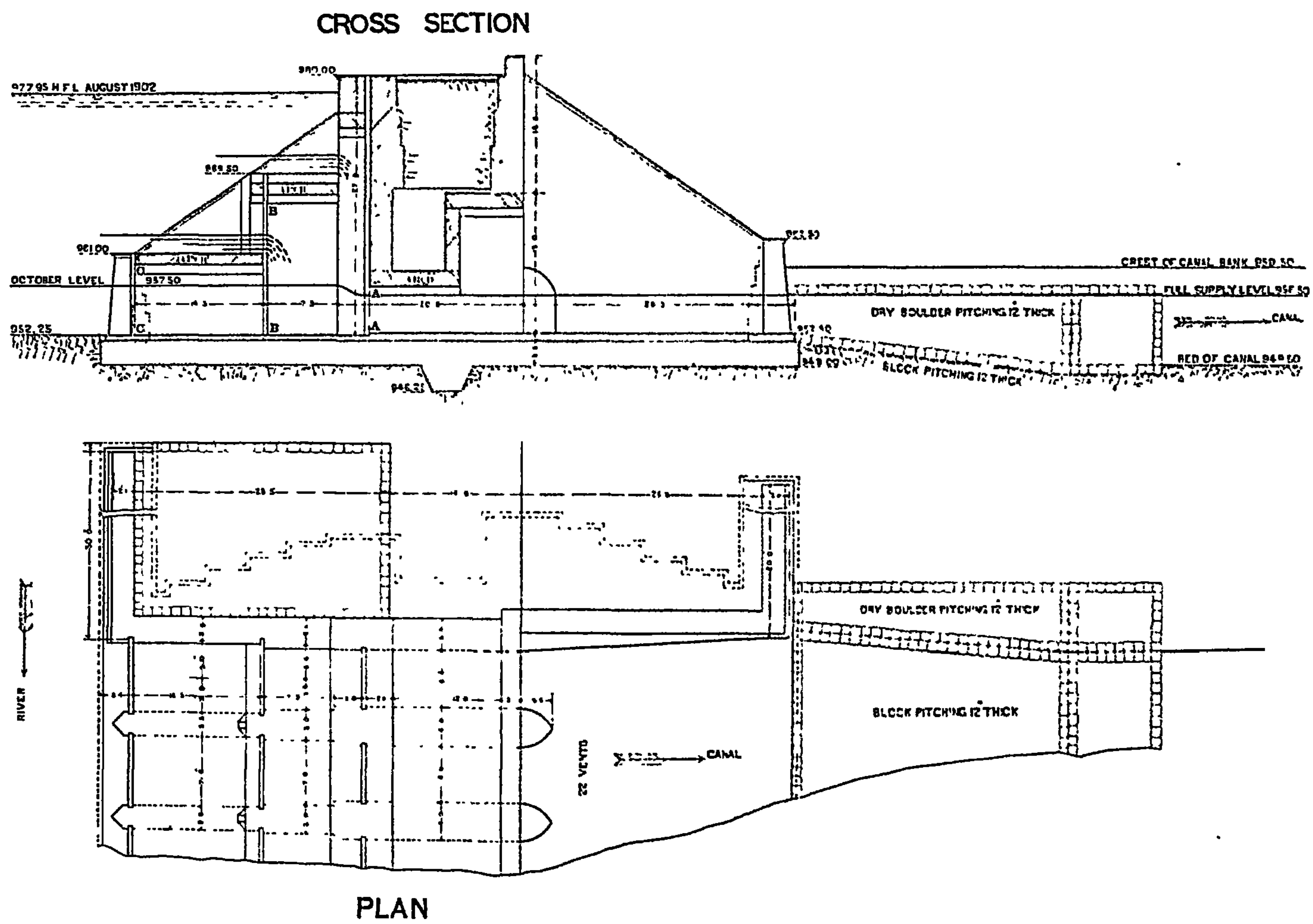
level of the floor. The vents do not extend down to the floor, but terminate on a crest-wall, which is at R. L. 717·00, 2 feet above the floor of the under-sluices. So there is a drop of 2·7 feet on to the floor of the head regulator, and that floor is 1 foot above the canal bed level. This raising of the level of the sill of head-sluices is a comparatively modern practice, and a wise one: it tends to prevent silt and to secure the discharge. Each vent in the Chenab regulator can be completely closed by a wooden drop-gate 10 feet high, which runs in a vertical groove. Each vent has two grooves, one for the gate, and one in front of it. The object of the latter is to receive regulating planks or "kurries," which form a raised sill, over which the water is drawn into the canal. It is customary to raise this temporary sill to R. L. 718·5—that is, 3½ feet above the floor of the under-sluices—at certain times in order to exclude heavy silt. The drop-gates are raised by a winch, which travels along the parapet wall, and are dropped, by their own weight, by releasing a suspending loop off the bar, on which the gate



HEAD REGULATOR OF THE CHENAB CANAL.

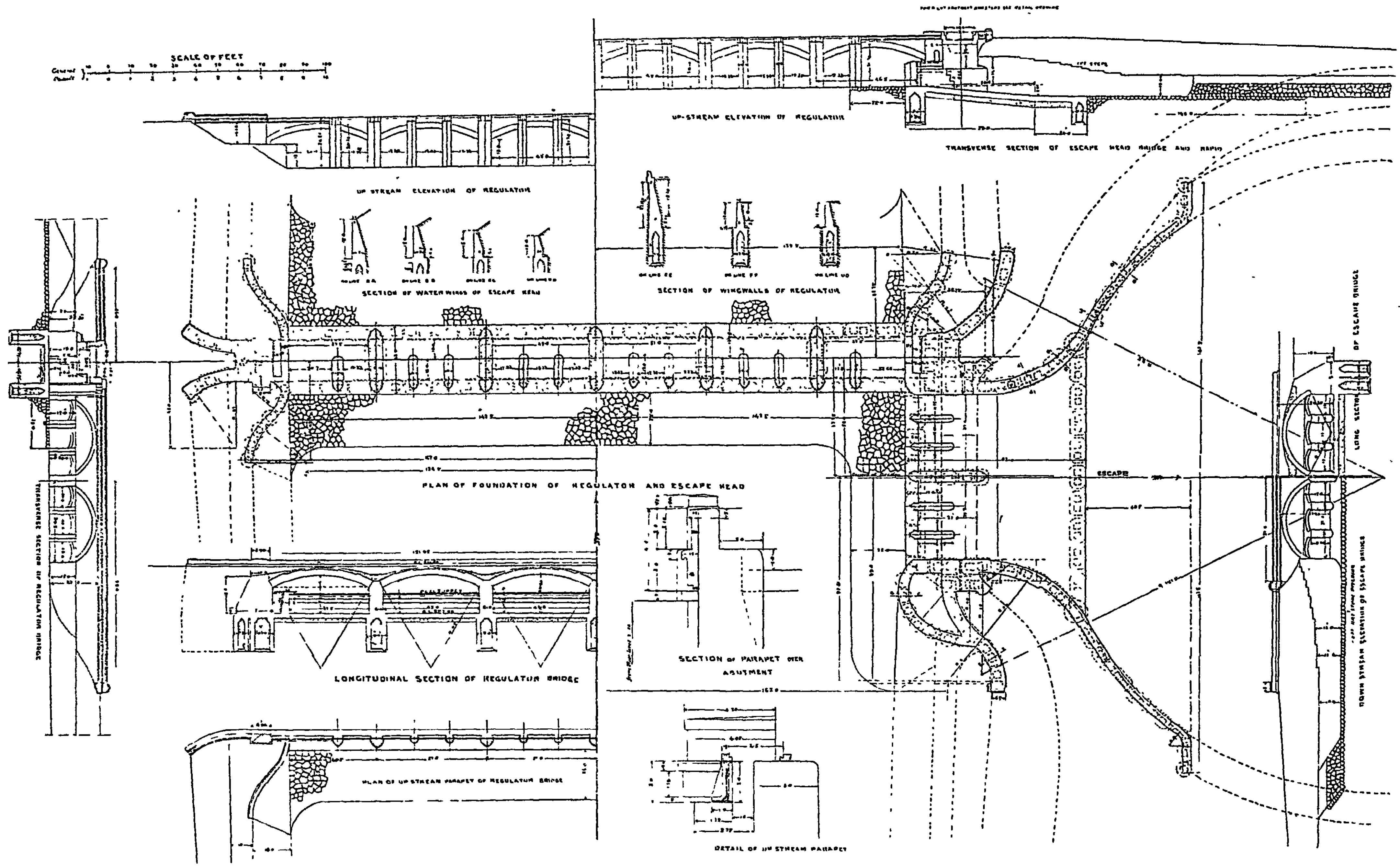
hangs when it is lifted. Flood warnings are sent by telegram from a point 80 miles up the river. When these warnings indicate that a high flood may be expected the gates in the regulator are dropped as soon as the water has reached R. L. 732·00, which is about 12½ feet above the temporary sill, and the canal is closed until the flood has fallen.

The Trebeni Canal head-sluice, which is now under construction in Bengal, stands on the bank of the Gunduk river, at a point where the flood rises over 20 feet. The sluice is designed to give the required discharge with a depth of 2 feet of water flowing over the tops of "kurries"

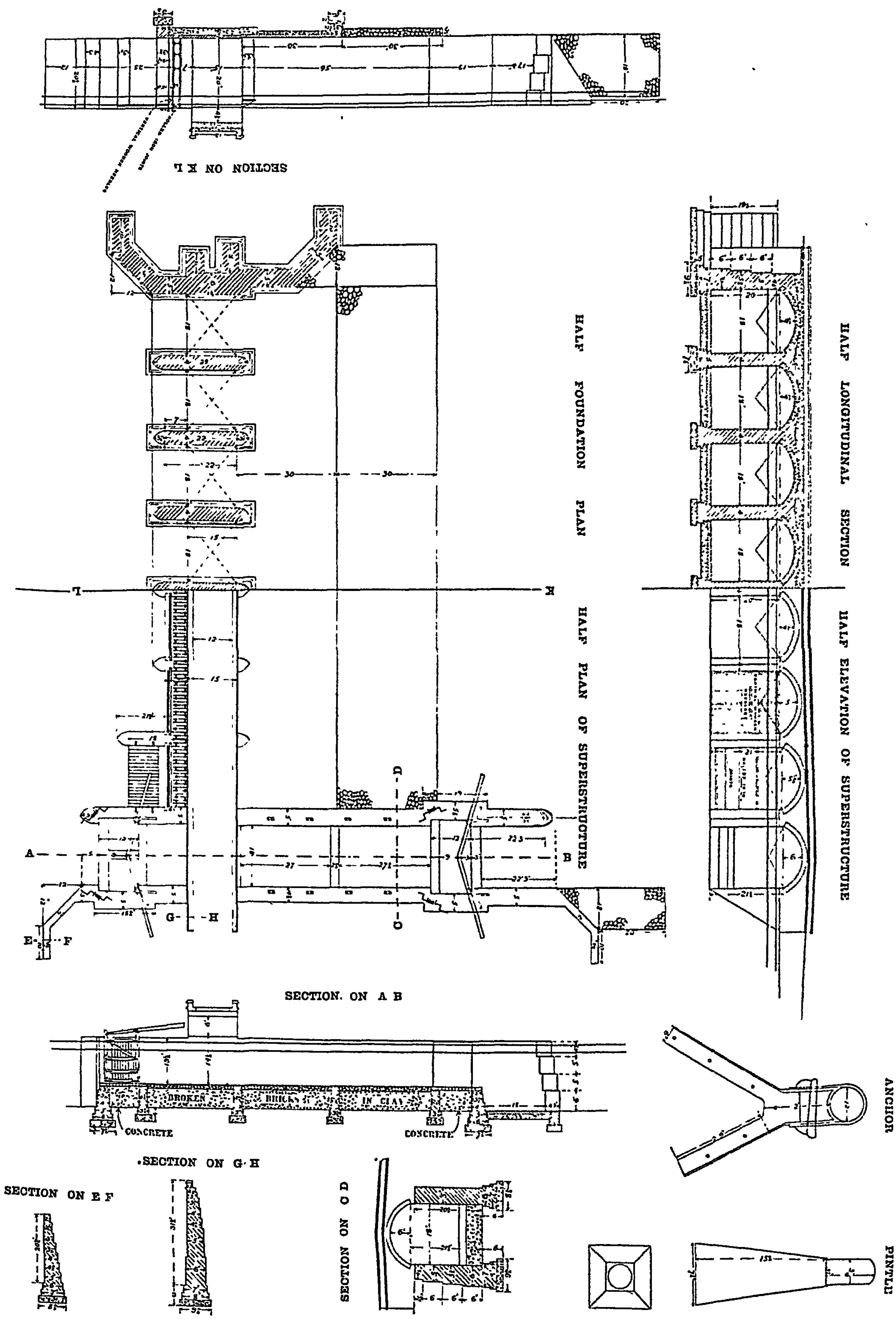


HEAD-SLUICE OF THE TREBENI CANAL.

or horizontal baulks. The vents A A have draw-gates, worked by a screw and capstan on the parapet. These vents will be used to some extent for regulation, and will be closed entirely if the high floods carry down heavy silt, which would be likely to choke the canal. When the flood level is more than 2 feet above 969·50 the supply will be drawn in over the top of the arched platform which lies at that level: at that time the vents B B and C C will be entirely closed. As the flood falls below the platform the "kurries" in the vents B B will be removed, as required, and the water will be drawn in over the top of them into the canal. When the water level in the river falls to less than 2 feet above the top of the platform at 961·00 the



CHAMKOUR REGULATOR AND ESCAPE, SIRHIND CANAL.



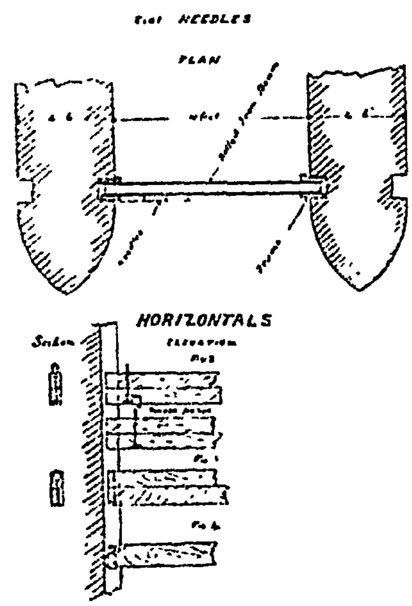
ALIPUR REGULATOR ON THE FULELI CANAL IN SIND.

"kurries" in the vents C C will be removed, as required, and the discharge will be regulated over the tops of the "kurries" in those vents.

Regulators within a system of canals are generally situated either at the point of bifurcation of a main canal, or across the channel immediately below an escape: in the former case the regulator is required in order to divide the discharge between the branches in the required proportions, and in the latter case to regulate the discharge of the canal by compelling the surplus water to flow off through the escape instead of down the canal.

A plan of the Chamkour regulator on the Sirhind Canal is given on page 211. In this and in the Doraha regulator, on the same canal, draw-gates worked by travelling winches are used. But the system of regulation by baulks is more common and is less expensive. There is rarely a head of more than 6 inches or 1 foot on these works, and baulks can be easily manipulated.

In the Sind inundation canals the regulators are usually worked by a system of vertical needles. The needles are driven down by a maul, and usually raised by a lever on the parapet wall. The Alipur regulator (Plate, page 212) is one of the more recent of these works: the floor seems a very light one, but the head on the regulator is not great, being rarely more than 4 feet. The greatest difference between the up-stream and down-stream level was in 1904, when it was 6·8 feet. The needles in this regulator are raised by a lifting apparatus which runs on a small truck on rails laid along the face of the work. The Alipur regulator has rolled iron joists, fixed horizontally, to receive the needles, but in most cases wooden baulks are used. The horizontal baulks which bear the pressure of the vertical needles are fixtures, usually, in the masonry. This system is employed in many regulators, such as that on the Eden Canal in Bengal. In Bombay, Mr. Whiting introduced the use of needles made of sheet steel, which have been successful.



NEEDLES AND HORIZONTALS ON EGYPTIAN REGULATORS.

This system of regulation is largely used in Egypt, the horizontal beams which bear the pressure being generally made of rolled iron joists. The regulators themselves are simple bridges with vents generally 10 feet wide, piers about 5 feet thick, and the crown of the arch at the high-water line. The depth to be controlled on Egyptian canals is very great: it is often 20 feet, and sometimes as much as 28 and 30 feet. The horizontal beams are not always fixtures in the masonry, but are lowered into place in a framework when they are required. A pair of shear legs is erected on the roadway of the regulator, and this frame is built up as it descends; it consists of four planks about 15 inches by 6 inches in section, two of which are inserted in each vertical groove of the regulator; between these planks the horizontal iron beams are bolted; they are put in place as the frame is lowered by the tackle on the shear legs, and are about 3 feet apart at the bottom of the frame, and the spacing is increased at the top according to the pressure. The needles generally used in Egypt are shaped as shown in the sketch, Fig. 1, and are about 10 inches by 6 inches or so: they are made of pine. But the system of regulating by vertical needles is tending to give way in favour of regulation by horizontal baulks or planks. The planks are about 10 inches broad and 4 inches thick, and they are raised by means of a fixed windlass over each vent. The difficulty is to get the planks down when a stream is flowing. The system adopted is to drop the planks one above another into the

grooves and to jump them down with an iron monkey. The men get very expert at dropping the planks horizontally so that they do not jam in the grooves. The planks used to have eye-bolts in them, as in Fig. 2, by which they were fished with a hooked rod, but it was found difficult to catch the eyes in a strong stream. The system in Fig. 3 was then adopted, where the eye was under the protection of the groove. But the most approved plan is shown in Fig. 4; in this case the hook can be fished by a rod with an eye, instead of a hooked end, which is an advantage, as the eye is stronger, and the strap round the plank is found to be better than the bolt through it, as it does not weaken it.

There are several causes which render it necessary to háve means of discharging water from a canal into a river or into a channel leading to a river. In the first place it not infrequently occurs that a heavy fall of rain puts an immediate check to, or perhaps will completely stop, all irrigation within a few hours. The cultivators close the outlets leading to their little channels, and the heads of the distributaries have to be closed or the banks will burst. The closing of the distributaries makes it necessary to reduce the discharge of the canal, or the same result would follow; but this cannot always be done in time to prevent a larger discharge passing down than the channels are able to pass forward, or, if it is possible to carry on the discharge, it must be escaped from the canal system somewhere, if the cultivators will not utilise it on the fields. Escapes are in some cases necessary to carry off, from the canal, drainage water which may have been admitted into it through inlets; and they are of service when any accident to a masonry work, or breach of the canal, renders it necessary to reduce the discharge immediately. Reference has already been made (page 38) to the use of escapes for scouring out silt deposits at the heads of canals when there is a sufficient volume of clear water available, after the flood season, to permit of water being run to waste. In Southern India escapes are usually termed "surplus sluices," and they are not infrequently used for the purpose just indicated. As a rule it is desirable to have sufficient power of escape on any canal to dispose of about two-thirds of the full discharge at the head: in distributaries of short length no escapes are necessary, but when they exceed about 10 miles in length, escapes, capable of carrying about one-third of the head discharge, add greatly to the ease with which they can be managed: and in some cases, especially where large tracts of rice are under irrigation, escapes are necessary to prevent the surplus water, which would otherwise flow out of the tail of the distributary, being used in an unauthorised manner for irrigation.

In the case of main canals, and also in long distributaries,[1] escapes are most desirable, indeed, in some cases, essential, not only at the tails, but at intermediate points. Where a branch canal takes off a main one, or where a large distributary takes off a branch, it is most desirable to provide an escape so that the supply of the subsidiary line can be immediately cut off without increasing the discharge of the larger one below the point of off-take. If possible an escape should have its vent into a river, or marked waterway, and not into a drainage line. On the Sone Canals, in Bengal, considerable friction with the people has, in some cases, occurred where this principle has been infringed. It is hardly possible to prevent occasional damage to crops, when irrigation channels have escapes into lands which are sometimes cultivated, and this is the case in many drainages. It is, in most cases, well worth while to increase the cost of an escape materially in order to carry the discharge into a well-defined waterway.

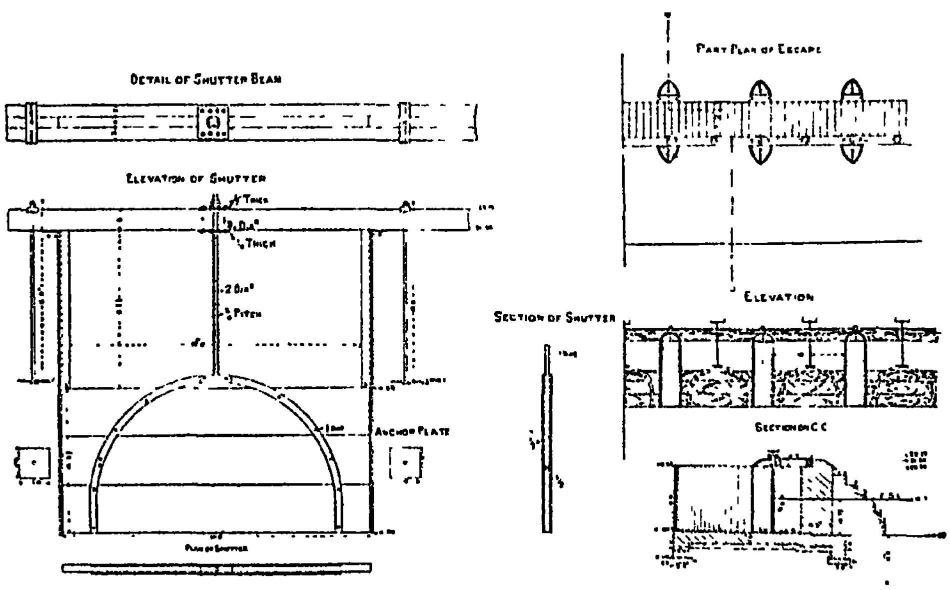
Escapes sometimes take the form of head-sluices with draw-gates, as in the Plate opposite this page, where the gates completely close the opening when they are down. In some cases, as in the following sketch, which is typical of the escapes—or surplus sluices as they are called—in Madras, the gates are worked in the same way as in the previous example, by screws,

[1] Lecture by C. W. Odling, Esq., C.S.I., delivered at Sibpur Engineering College, Feb. 23rd, 1893.

but they do not close the vents: the crests of the gates, when down, are at full supply level, and a moderate amount of surplus water can be permitted to flow over the top of them when the water in the canal rises.

In other cases, an escape in the form of a canal weir such as shown in the Plates on pages 219 and 220 is used, in which the planks above the weir crest can be removed at pleasure: this form of escape is most suitable when the canal is in embankment. When an escape is constructed simply for scouring purposes, the draw-gate system is preferable to one worked with planks or baulks, and it is desirable to have a drop in the floor of the work, and a free discharge for the water in the escape channel below, so that the flow may not be impeded. When escapes are in the form of clear overfalls, and indeed in other cases too when the channel below the escape runs dry, it is essential that the floor below the outlet should be very strong, or that a good water cushion should be provided, as escapes are occasionally opened very suddenly, and a very heavy action on the floor follows.

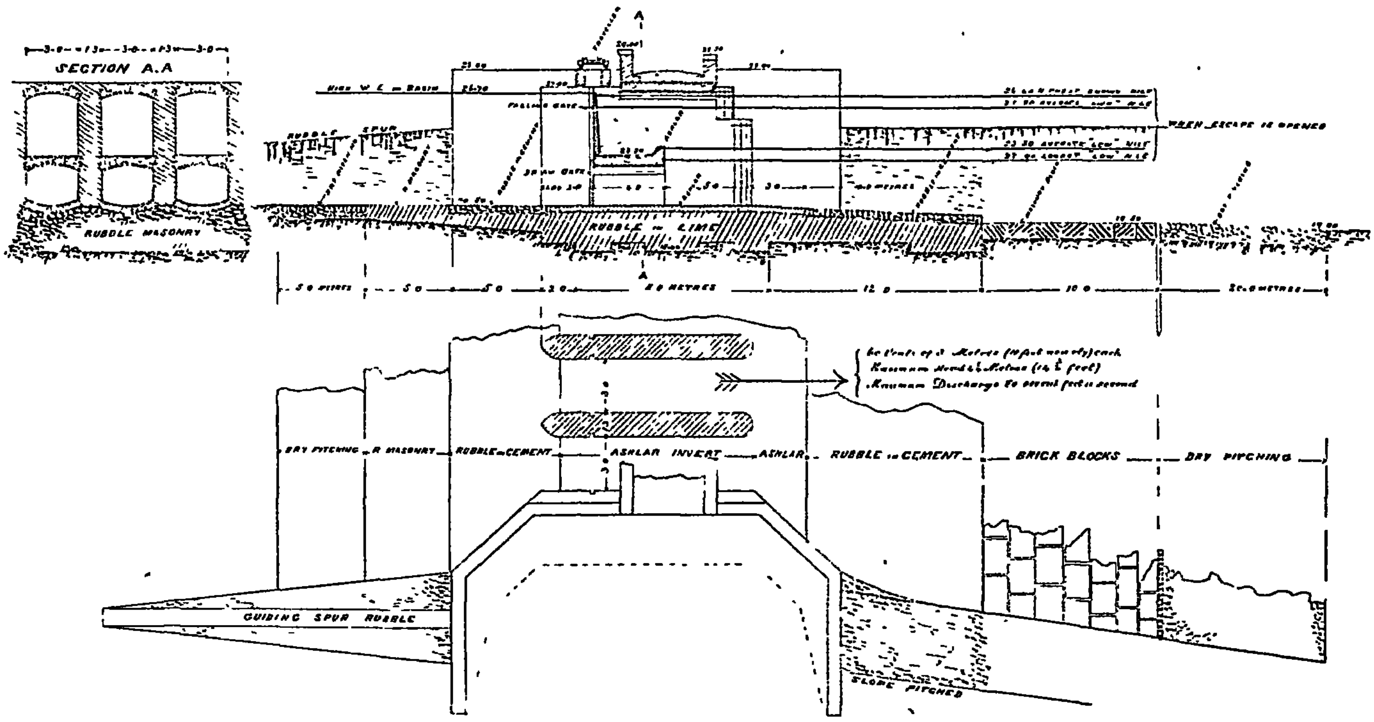
In many cases, circular basins, having a diameter of two and three times the width of the channel, have been scoured out below escapes and regulators; these pools are occasionally cut out to a great depth, and threaten the wings and the floors of the work. In old designs the floors, and the pitching below the floors, was usually horizontal; the latest practice is to construct these works with a long sloping masonry talus, commencing generally from the lower curtain wall, but sometimes from the piers, having a crest slope of 1 in 10; and to carry a dwarf wall along the side of the channel, which takes off from the wings, running parallel to the centre line of the channel. This wall has been found to have a very good effect in directing the flow of the water, and in preventing the action on the sides of the channel; the height of it need only be from one-third to one-half the depth of water, but the slope above it must be strongly pitched. In place of this dwarf wall the majority of the engineers in Egypt prefer to construct a dry rubble spur with a masonry footing only. This is much less expensive than the dwarf wall, and has the advantage that as it is less rigid it gives way to any settlement which may occur. A very similar plan has been adopted on the Eastern Jumna Canal, in the Punjab, on a small scale, to stop the pooling below distributary falls; but the dwarf walls are kept above water-line at the wings, and the crests slope at an inclination of 1 in 5, and the slope is carried right down to the bed level at the end of the wall. The rule in these cases is to make the length of the wall from five to six times the depth of the water. The experience of Egyptian regulators and escapes shows that spreading wings, or wings opening from the side walls in a curve, are a mistake, and that the best methods for stopping erosion on the sides and



ESCAPE, OR SURPLUS SLUICE, IN MADRAS.

bed are, first, by giving depth and not width to the channel; and, secondly, by forcing the water, and more particularly the lower strata of the stream, to follow a course parallel to the centre line of the channel. In more than one case pooling which threatened to destroy a regulator has been stopped by rough rubble spurs laid from the side line of the abutment, through the pool, parallel with the centre line of the channel.

The Qushesha escape in Egypt, shown in the sketch below, is a magnificent work capable of discharging 80,000 cubic feet a second. It has sixty vents of three metres (10 feet nearly) each. The maximum head on it is calculated to be about 4·25 metres ($14\frac{3}{4}$ feet), and it may be necessary to open the entire escape when there is this difference of level. There are two lines of gates: the lower line consists of draw-gates, similar in design to those used on the under-sluices of the canals in Upper India (page 191); the upper ones are falling gates

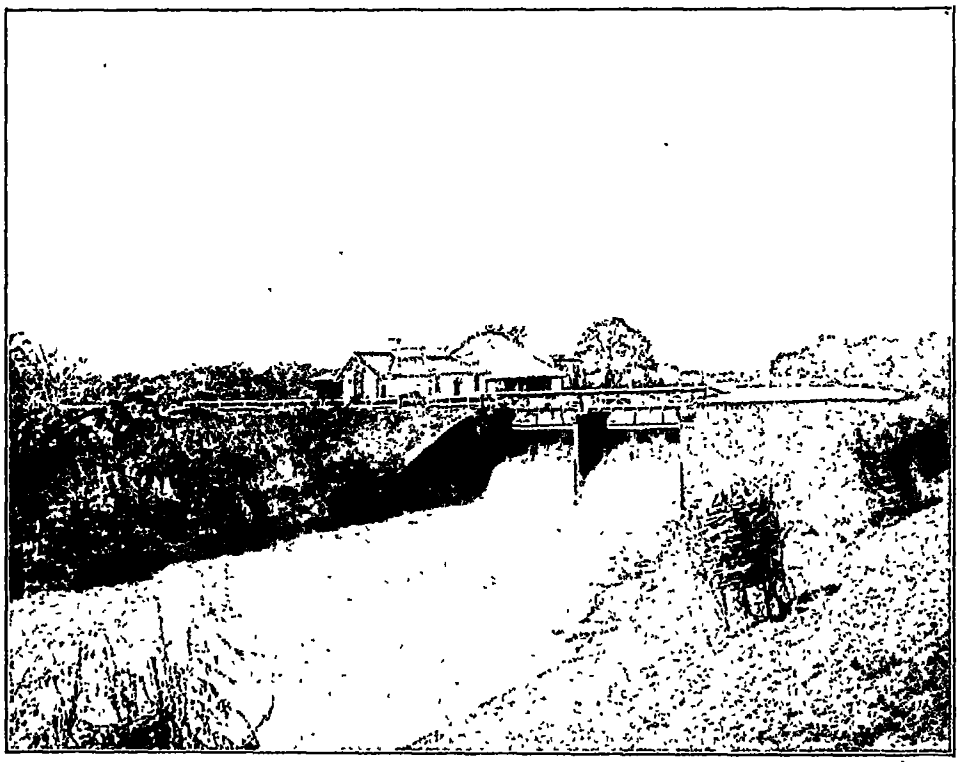


QUSHESHA ESCAPE IN MIDDLE EGYPT.

hinged at the lower edge. Both are of iron. The lower gates are $2\frac{1}{2}$ metres (8 feet 3 inches nearly) and the upper ones $3\frac{1}{2}$ metres (11 feet 3 inches) in height. The upper gates are for escape only. Two travelling cranes run on the top of the piers, which are used to raise the upper or falling gates and to lift and lower the draw-gates. The upper gates fall into a water cushion formed by the ashlar sill laid at the lower extremity of the upper floor.

This immense escape was opened for the drainage of the basin system for the first time on the 17th of October, 1891. For a short time previously thirty-two of the lower gates had been raised about $2\frac{1}{4}$ feet, to regulate the level in the Qushesha basin: on the date mentioned all of the sixty upper gates were released,[1] within a period of twenty minutes, by four parties of three men each, without a hitch. The whole number could have been released in ten minutes,

[1] "The Qushesha Basin Escape, Middle Egypt," by Major R. H. (now Sir Hanbury) Brown, R.E. Professional Papers of the Corps of Royal Engineers.



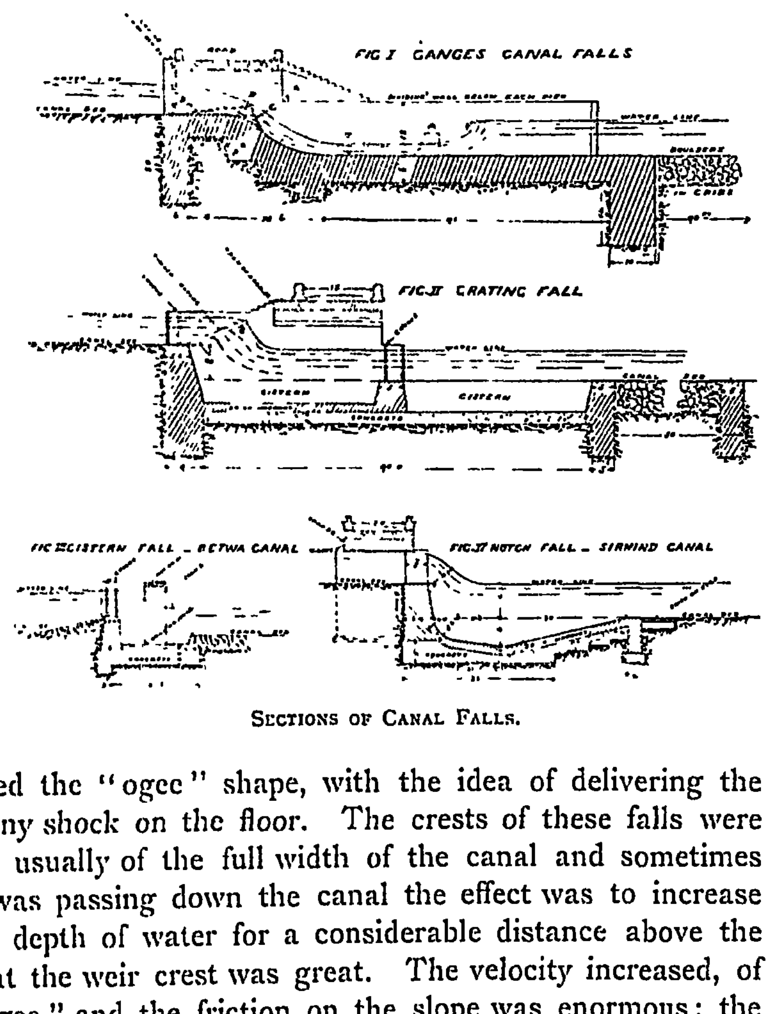
A Fall on a Bengal Canal.

Reri Bridge and Fall, Eastern Jumna Canal.

[To face page 216

but an interval was allowed in order that the spectators who had gathered to see the operation might alter their positions.

Canal weirs or falls are required at intervals on any canal in which the slope of the bed is less than that of the country in which it runs; for as the bed gains on the surface of the ground the water level becomes raised above it until a point is reached at which it is desirable to drop the water over a weir or fall and to commence a new reach of the canal. In canals which are designed for navigation as well as irrigation, a fall has to be constructed at each lock. The following sketches show some of the various forms of canal falls which have been adopted: the earliest ones in Upper India were those on the Bari Doab Canal. In the upper reaches of that canal rapids were generally adopted, and in the lower reaches, where boulders were not so readily obtainable, vertical falls (Fig. II.) were generally used, and a cistern was sunk below the level of the lower canal bed to form a cushion of water to resist the shock of the falling stream. This cistern at the down-stream end used to end in a vertical wall, as shown in the sketch, but it was found that the wear and tear on this wall was enormous, and reverse slopes are now usually adopted instead of the vertical wall. On many of the canal falls in Upper India it used to be the practice to fix gratings, as shown in Fig. II., just at the level of the weir crest, sloping up to the surface of the stream: these gratings were composed of timber beams, 4 to 5 inches thick, spaced 6 or 8 inches apart, lying in the direction of the current, so that the water was divided into a number of filaments. They still survive in some of the old weirs, but the principle is not a good one. On the Ganges Canals nearly all the falls were originally built on what is called the "ogee" shape, with the idea of delivering the water at the foot of the fall without any shock on the floor. The crests of these falls were at the upper canal bed level, and were usually of the full width of the canal and sometimes even wider: when a large discharge was passing down the canal the effect was to increase the velocity in it and to decrease the depth of water for a considerable distance above the fall, so that the velocity of approach at the weir crest was great. The velocity increased, of course, as the water ran down the "ogee," and the friction on the slope was enormous; the shock on the floor was reduced, but the friction did as much damage as the shock would have caused, and the velocity was so great, that a standing wave was created below the fall, and the washing of the banks was considerable.[1] These "ogee" falls have given endless trouble: they were constructed in brick, and the lower slopes were constantly torn up: ashlar was substituted in some cases at considerable expense. One plan which was first tried was to build cross walls as at A. These walls were swept away over and over again: they were

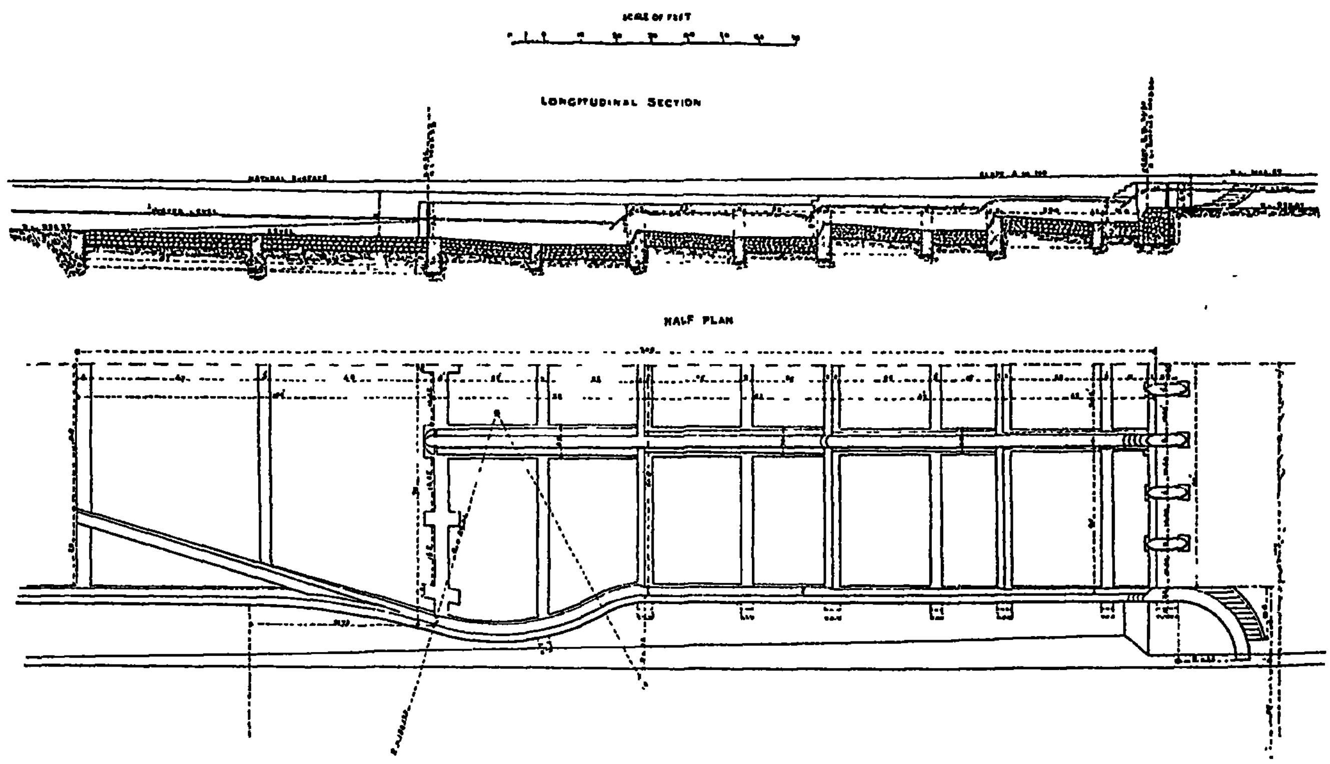


SECTIONS OF CANAL FALLS.

[1] See article 111, page 502, Unwin's "Hydraulics."

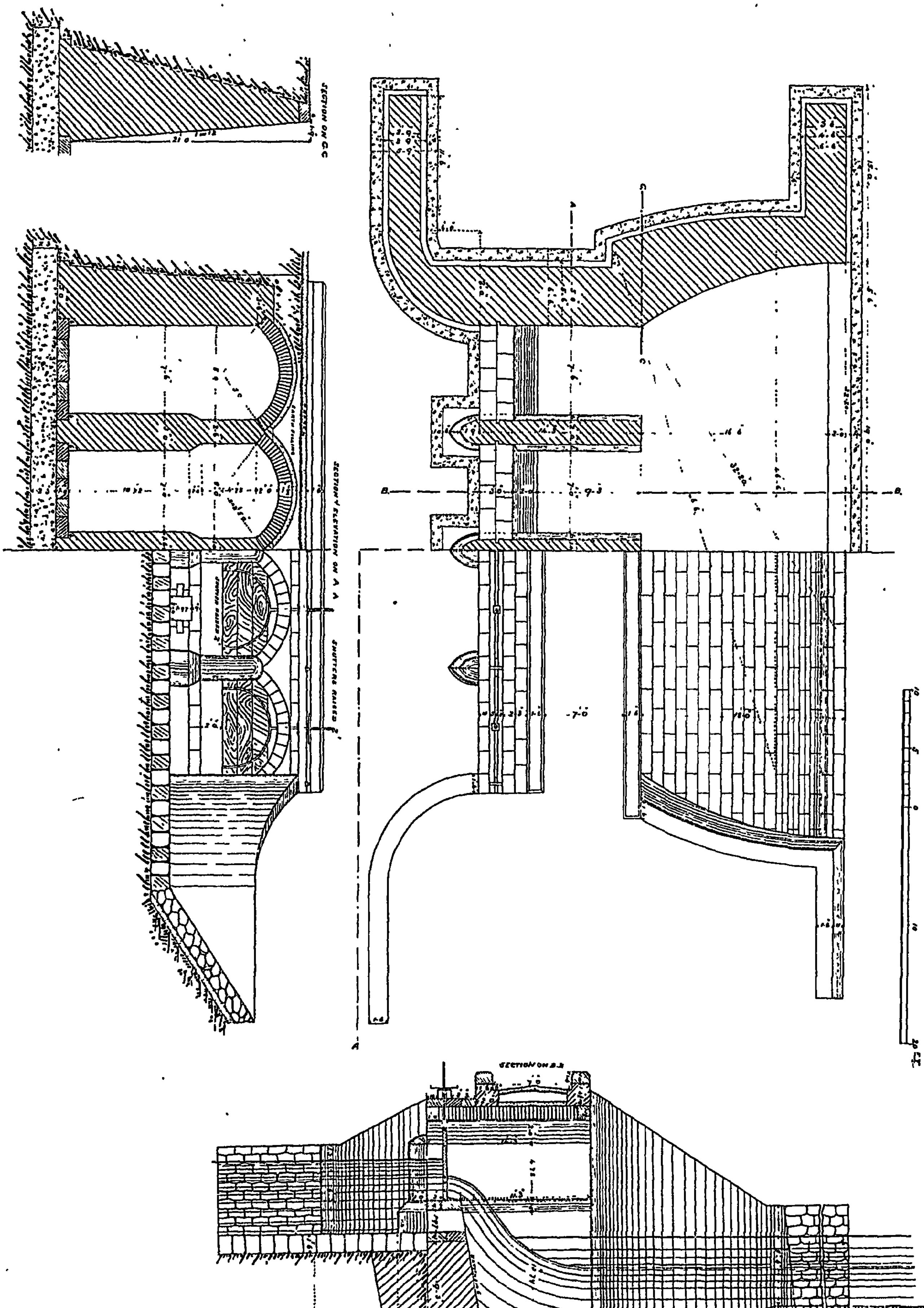
built of all kinds of materials: one, which was standing a few years ago (and may be still), was built of old cannon balls! Another plan was to build up the crest wall, as at B, in conjunction with the wall A. Then the "ogee" was converted into a clear overfall by the addition of a piece of masonry, as at C. In some cases the crest was raised, as at D: this was found to be the best plan of all, and the result was a near approach to the clear overfalls of Figs. II., III., and IV.

On the Bari Doab Canal, which has a rapid slope and high velocity, especially in the upper reaches in the boulder formation, many of the drops of the canal bed are effected by rapids. The sketch shows the style of work. One of the most striking of these is the one called the Cascade Fall: it looks extremely pretty, the water appears to pile itself up in great

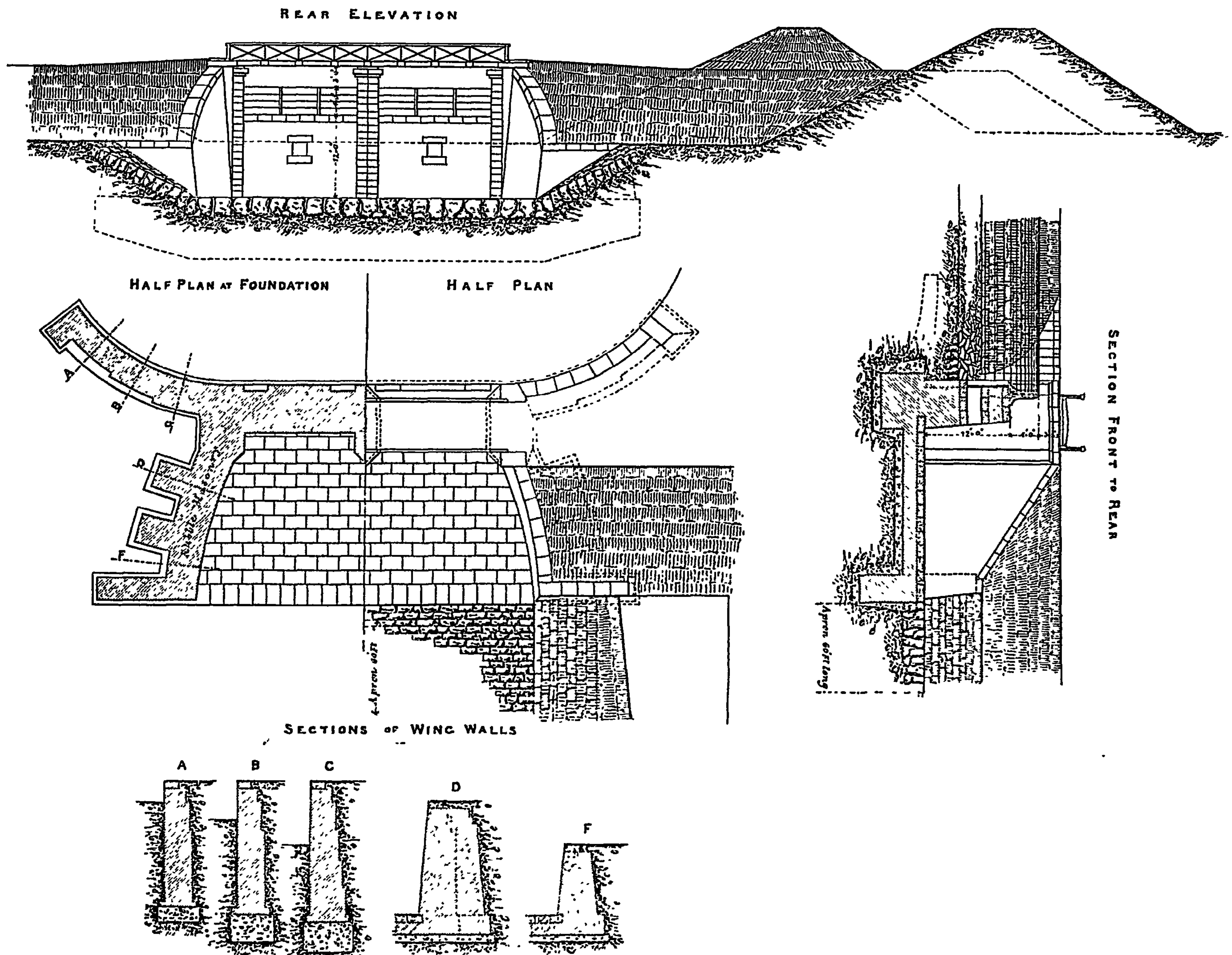


CASCADE FALL ON THE BARI DOAB CANAL.

rolls of fluid as it rises up to the crest of each succeeding drop. It will be noticed that below each drop there is a flat length and then a rising length of floor: the velocity below the drop, on the flat, is greater than on the rise, and a standing wave is produced which seems to endeavour to return up-stream as it rolls up to and over the drop. The converging wings at the tail of these falls are not good: they tend to produce scour of the bed. Dwarf walls parallel to the line of flow are best. The first 12 miles of this canal has nineteen falls and rapids, in addition to a slope of bed of 1 in 1,250; the banks are well wooded, and the channel winds sufficiently to give variety: the velocity in the canal, which is only 4 to 5½ feet deep, is from 4½ to 8 feet per second, and the water is usually clear and bright. The Cascade Rapid is altogether 320 feet in length, the dry boulder pitching below the masonry flooring being nearly 160 feet long, and could only have been economically constructed where stone was very cheap. The wings on either side are parallel to the centre line of the canal for the

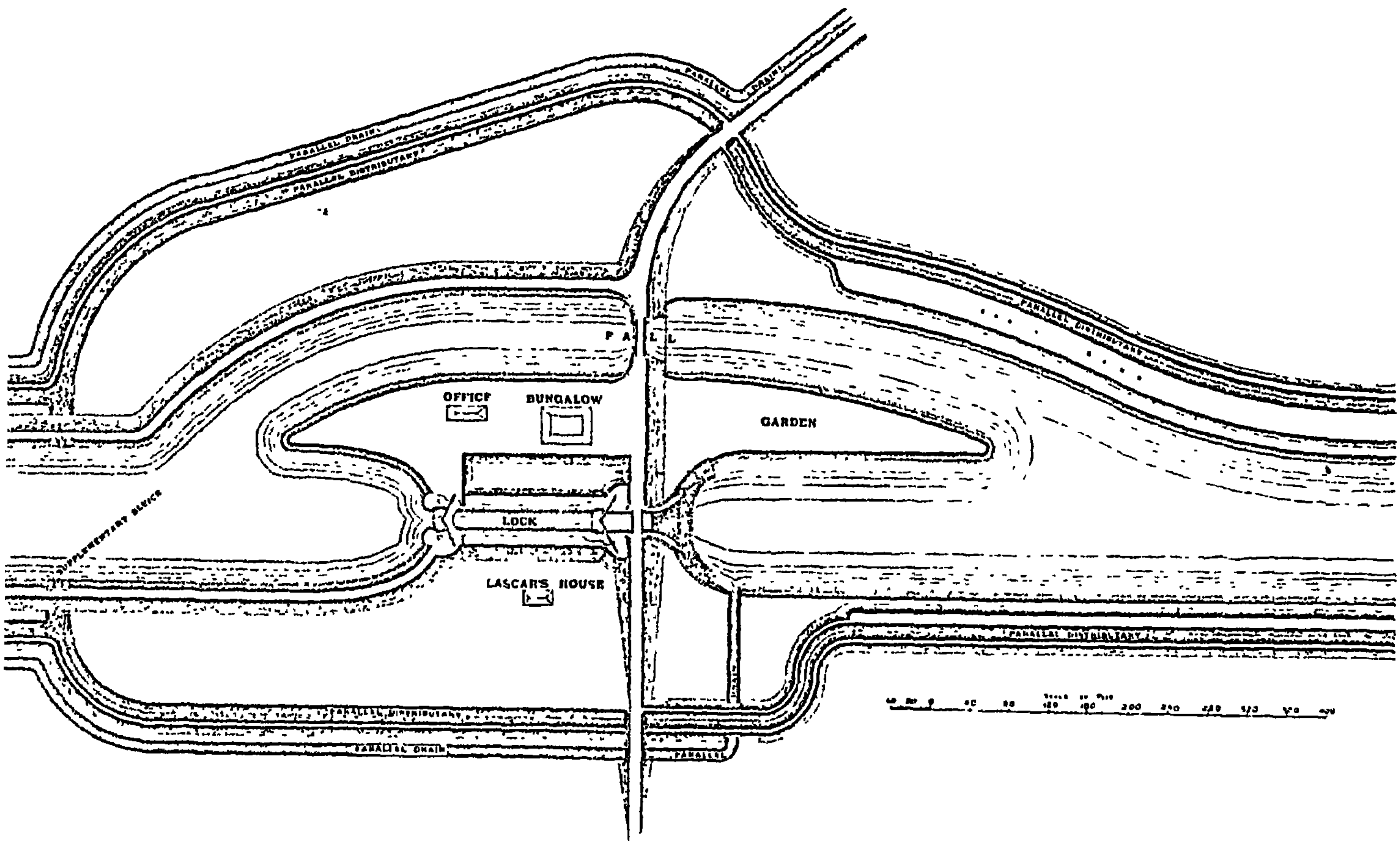


TYPE OF CANAL FALL IN MADRAS—KISTNA CANAL.



TYPE OF CANAL FALL ON BENGAL CANALS.

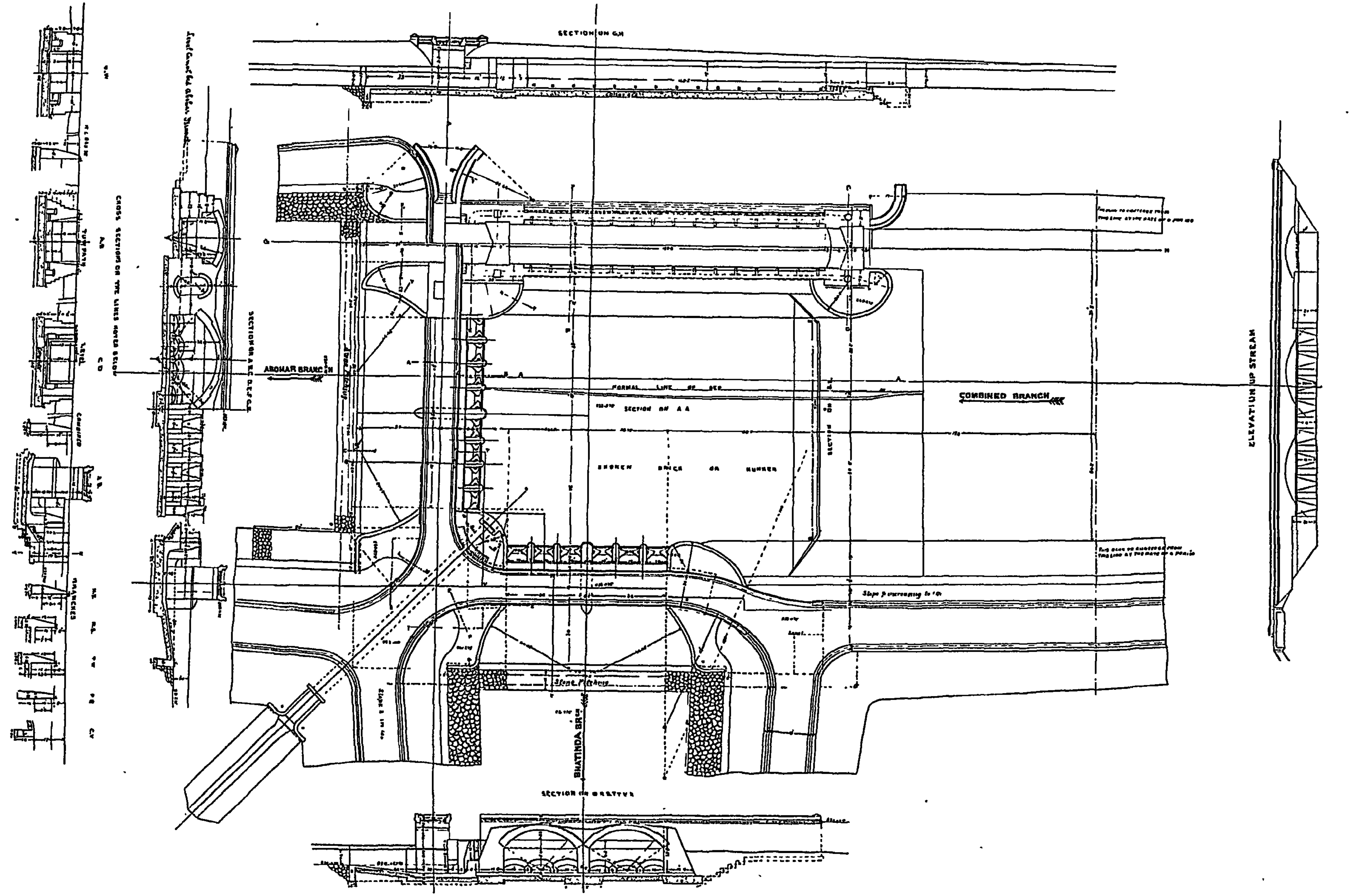
length of the masonry floor, and then in some cases they recede in a curve from the former line and finally slope toward the centre of the canal with the object of diverting the current from the banks. It is now held that converging wings below falls are a mistake and that either parallel wings or those diverging slightly are preferable. In many cases the wings on these rapids have been altered of late years and made parallel. The rapids on the higher reaches of this canal are all built with piers and grooves for planks, but these are seldom used. Light concrete arches are, in many cases, thrown across from pier to pier to form foot bridges. The ordinary rapids were originally formed of crates and boulders: there were longitudinal as well as cross rows of crates, but these crates have now been removed and masonry substituted. In the larger rapids these longitudinal and cross walls were laid in masonry in



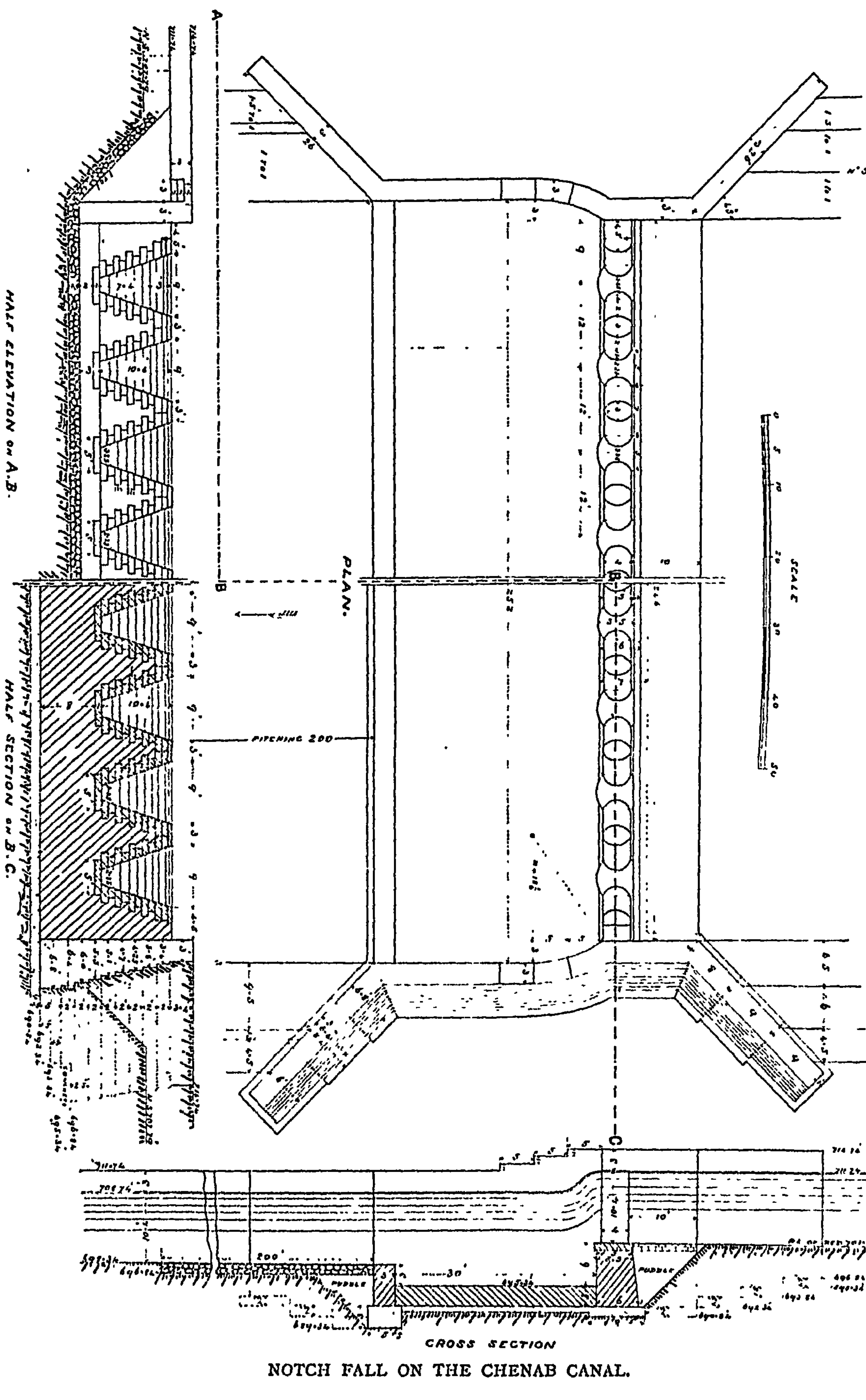
GENERAL PLAN OF LOCK AND FALL ON BENGAL CANALS.

the first instance, the square openings between them being packed with boulders 12 inches or 15 inches in diameter, but, when the canal was remodelled, the hand-packed boulders were removed and laid in mortar or in concrete.

In Southern India the practice was always in favour of maintaining a steady velocity in the canal up to the fall by raising the crest and reducing the width of it to that which was necessary for the purpose. This plan caused, of course, a somewhat greater drop than was obtained where the crest was at the canal bed level, and the width of it equal to or even greater than that of the canal; but the velocity of approach was less, and the action on the floor below was moderate. The Plate on page 219 shows a typical Madras fall, with a depressed floor or cistern below, but in many cases the floor is at the level of the canal bed; the Madras type has been generally followed in Bengal. The sketch on this page



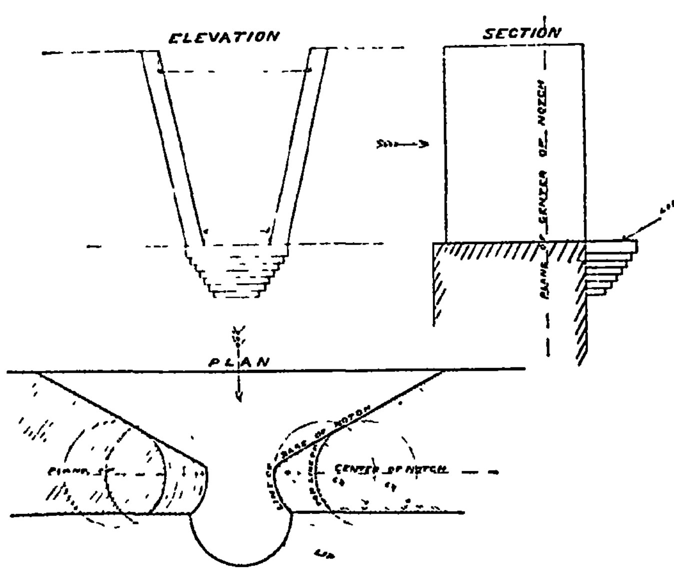
BHAWANI REGULATOR WITH LOCK AND FALL, SIRHIND CANAL.



NOTCH FALL ON THE CHENAB CANAL.

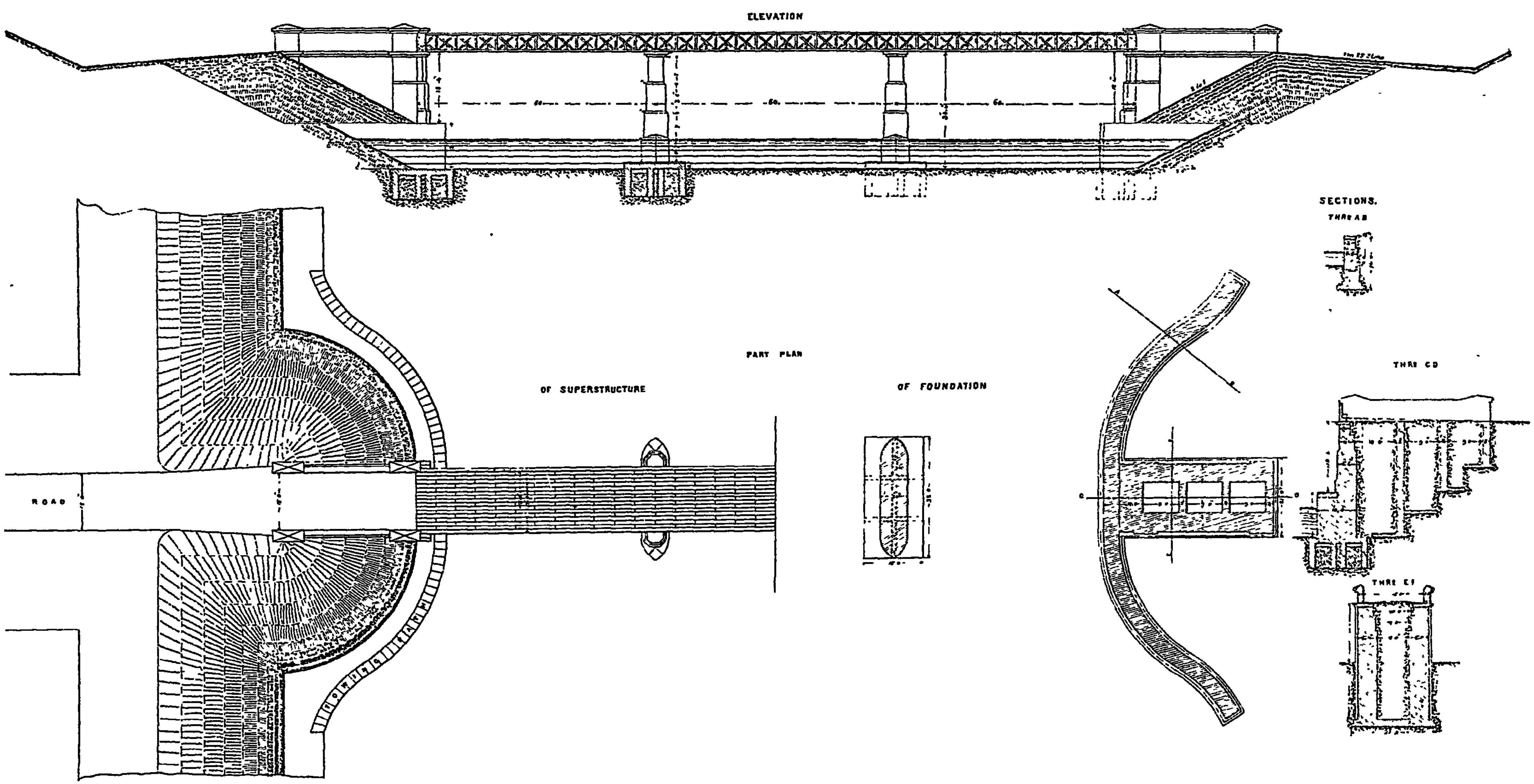
shows the general arrangement of a lock and fall in Bengal: and the Plate on page 220 shows a canal fall on the Midnapore Canal: those in Orissa and on the Sone are of the same description. In Bengal the custom is to have cast-iron brackets bolted to the crest of the fall with grooves for planks, but in Madras, although this system is employed, there are often draw-shutters lifted by screws from above as in the Plate on page 219. When planks are used, they are all kept to a uniform width, so that the discharge of the fall can be ascertained by reading the gauge above the weir and counting the number of planks in each bay. Tables are usually drawn up, and kept at each weir, showing the discharge at varying levels when different numbers of planks are in place. A light bridge over the fall enables the attendants to get at the planks, which are lifted by chains which can be attached to hooks on the planks.

In canals where navigation is allowed it is often necessary, when a very small discharge is passing, to impound the water in the reaches by boarding up the falls above the level at which the canal runs when carrying full supply, and to reduce the water in the reaches almost (or it may be quite) to a horizontal plane. In these cases it is best to raise the crest of the fall and widen it (suitably for the full discharge) so that the depth on the crest may not be unduly increased. There is always the danger that the men will impound the water and then suddenly open the weir (perhaps to flush down a boat stuck in the shallow water below) and thus throw an excessive strain on the lower floor. It is usually considered in Bengal that 3 feet 6 inches to 4 feet is a sufficient depth of water on the crest of a fall when it has to be regulated by boards.

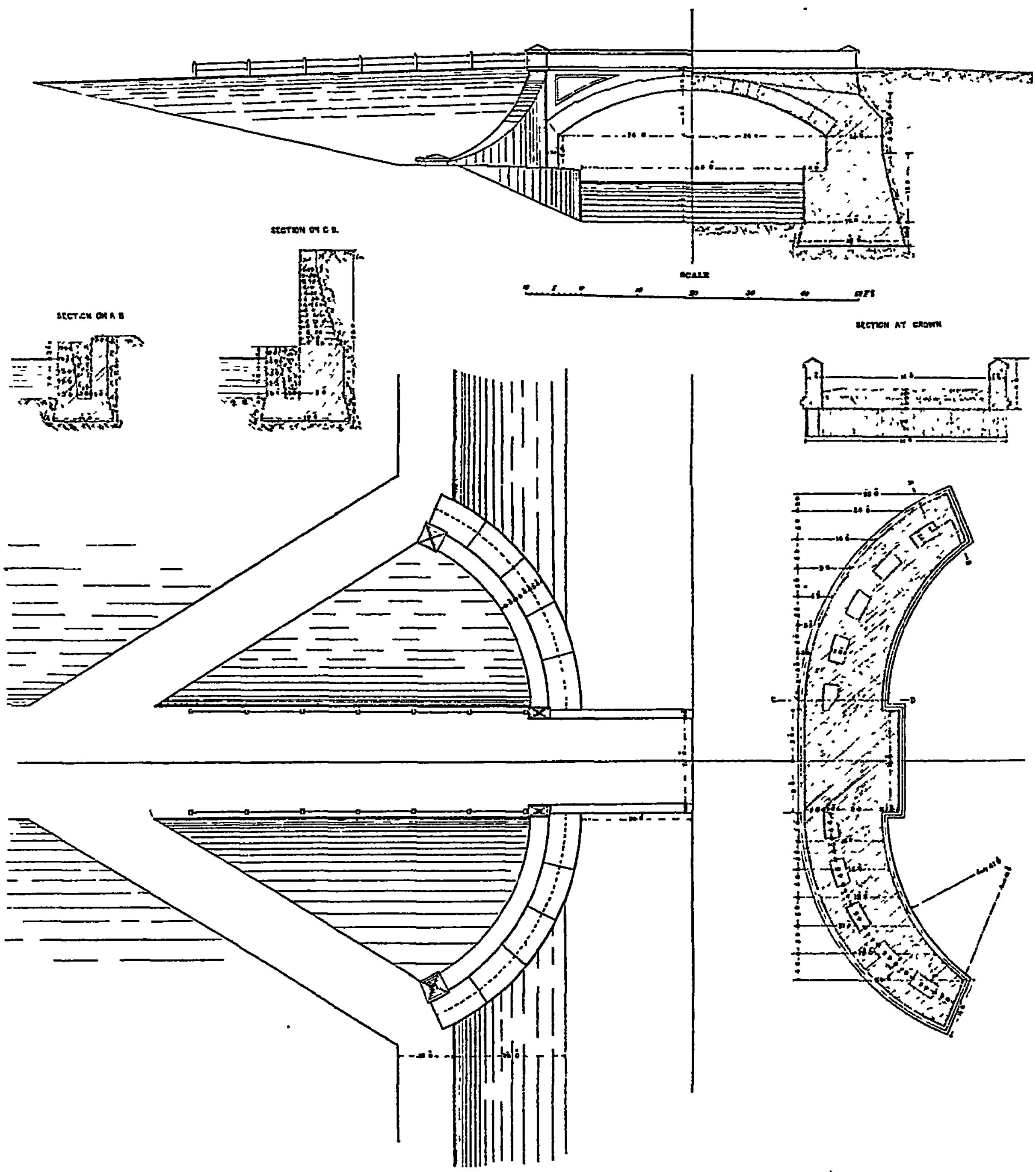


FORM OF NOTCH USED ON FALLS IN THE PUNJAB.

When the discharge of a canal is fairly constant there is no necessity to impound the water in the reaches for navigation; and in canals where navigation is not practised, it is never necessary to do so. In these cases there are very great advantages in adopting the form of canal fall which has been so successful on the great Canals in the Punjab. In this design the difficulties of excessive velocity and great action below the fall have been overcome. The Plate on page 222 shows a lock and fall on the Sirhind Canal, and Fig. IV. on page 217 gives a section through the breast-wall of one of these falls. The Plate on page 223 is a typical design of the notch falls which have been constructed on the Chenab Canal in the Punjab. The breast-wall of the fall is cut into a number of notches of which the bases are at the canal bed level, the crest of the breast-wall being above full supply level; at the foot of each notch there is a lip projecting beyond the lower face of the breast-wall, which has a great influence in spreading the stream and determining the form of the lower face of the falling water. The notches in the wall are all alike, and they are so designed that they discharge at any given level the same amount of water approximately as the canal above carries at that level, so that there is no increase in velocity in the canal as the water



TYPE OF GIRDER BRIDGE ON BENGAL CANALS.



OVER BRIDGE ON THE BUXAR CANAL, BENGAL.

approaches the fall,[1] but a uniform flow and a uniform depth is maintained. These notches work most sweetly. The water flows from them in a fan-like shape and meets the water surface below with a steady flow which contrasts most favourably with the violent ebullitions which accompany all other clear overfalls, and there is no vestige of the standing wave which is produced in falls which permit of a greatly increased horizontal velocity. The action on the canal banks below these falls is very small although the wings are of very moderate length. There is no question of the superiority of them over all others where the circumstances admit of their being adopted. They are universally used throughout all the distributaries of the Sirhind Canal, where no heading-up of the water by planks at the falls (which is so common in Bengal and Orissa) is permitted. It will be noticed from Fig. IV., page 217, that the form of the floor below the fall is peculiar; it has great depth immediately below the point where the greatest shock from the falling water has to be received, and it slopes up from that point to the level of the canal bed. This form is peculiarly suitable for checking the ebullitions of the water and reducing it to steady forward velocity, and is based on the same principle as that on which the form of floor below Egyptian regulators and escapes has been determined (page 215). At the end of the floor the water flows almost quietly into the canal. There is hardly any pitching required on the canal bed below the floor. The rising floor was adopted in Madras for canal falls before it was introduced in Upper India, but the curved form of the toe of the breast-wall and the position of the deepest point below the point of maximum impact is peculiar to the Punjab.

Although this form of fall is very good, the depth of the foundations adds considerably to the difficulty of construction, except when the soil is very hard. In many cases, especially where ashlar is not very expensive, it may be cheaper to protect the floor by mere strength of materials than by the deep cushion which this form of section affords.

A series of experiments[2] on the best form of notch was carried out by Mr. Benton: he showed from theoretical considerations that the form of notch which would discharge with absolute accuracy the quantity of water carried by a trapezoidal channel with any depth of water in it, was one with a curved base and sides of a certain form, but he proved that a trapezoidal notch might be made which would be quite sufficiently accurate for all practical purposes. The form of notch which was approved is shown in the sketch on page 224.

Bridges over Indian canals vary very widely in design. Of late years iron bridges with wooden roadways have been more largely used, but they are very expensive in repairs. The Plates on pages 225 and 226 are typical cases of bridges on Indian canals. As a rule it is not desirable to restrict the waterway of a canal or distributary at the site of a bridge by more than 30 per cent., owing to the various disadvantages due to any alteration in the velocity of flow of the water. In navigable canals in Bengal a headway of 15 or 16 feet is necessary to provide for the easy passage of the majority of native boats.

[1] Except for a few feet close to the notch.
[2] Report by Mr. Benton on "Hydraulic experiments to determine the most suitable form of notches"—1879.

CHAPTER XIII.

CROSS DRAINAGE WORKS, SUPER-PASSAGES, AQUEDUCTS.

Drainage crossing Canals—Inlets and Escapes—Rutmoo Torrent, Ganges Canal—Danger of Canal being Blocked—Budki Super-passage—Siswan Super-passage—Solani and Kali Nadi Aqueducts—Aqueducts in Bengal—Thapangaing Aqueduct—Syphon Aqueducts—Burra Bubsa Syphon—Velocities in Syphons—Difficulties connected with Syphons in Flat Drainages.

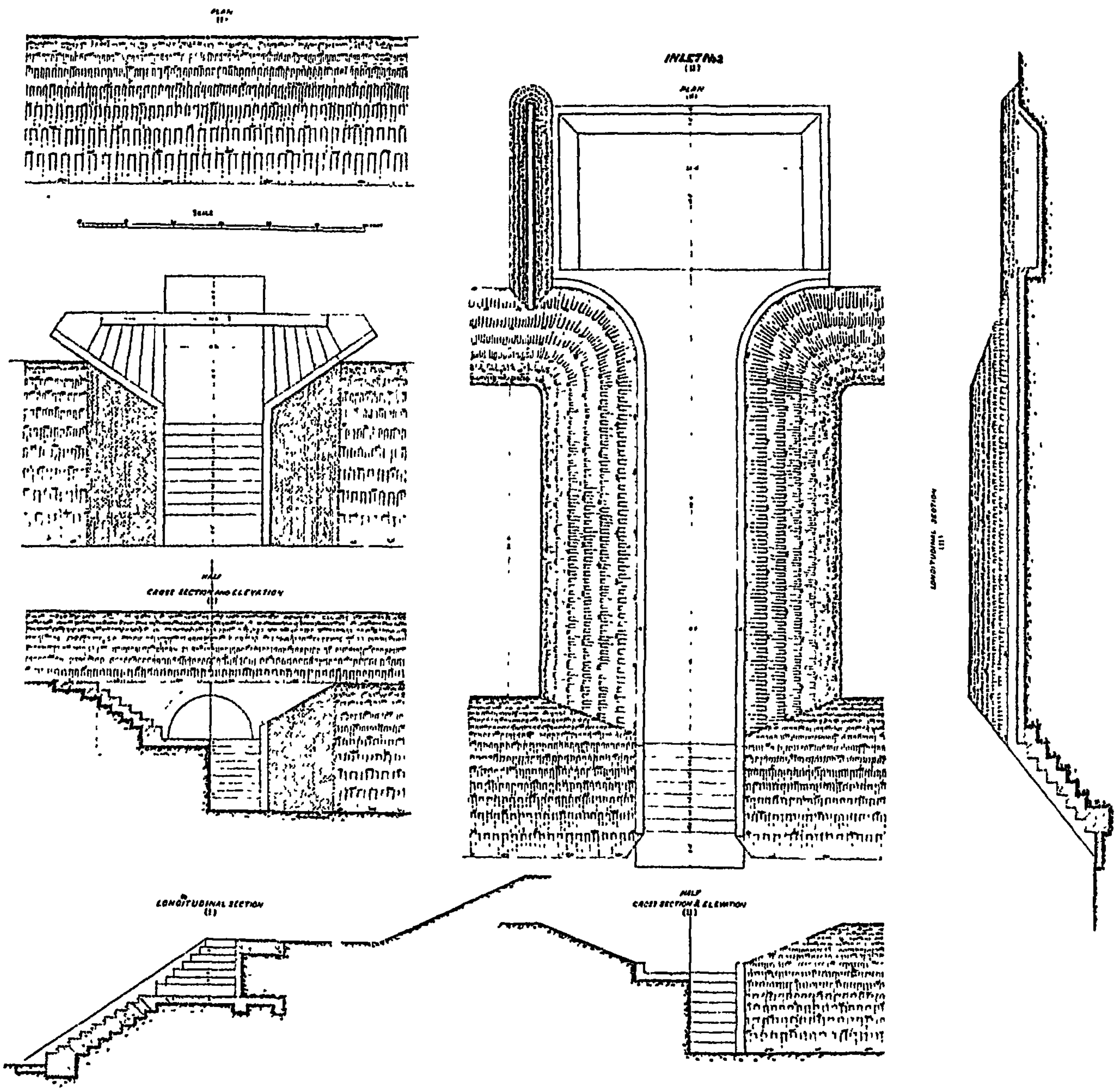
An irrigation canal is best placed when it runs on the crest of a ridge, and when the drainage off the neighbouring country flows from it on either side. Such an ideal position, however, is rarely attained by any canal during the whole of its course, except perhaps in some cases in deltaic systems, and usually it is necessary to carry the alignment of a canal across one or more drainages or streams before it can be laid down on the ridge. This is more particularly the case when a canal is compelled to run on a contour at the foot of hilly ground—as frequently occurs with the upper canal in a deltaic system, and almost always with canals leading from reservoirs—when drainages must necessarily cross it at right angles; or, when a canal takes off the higher portions of a river in the neighbourhood of the hills, where it is not so easy to divert the drainages and streams as it is in the easier gradients of the plains. The cost of the works necessitated by cross drainages is often considerable, and in some cases—as in the Ganges and Sirhind Canals—it may exceed the cost of the head-works themselves. Cross drainages when the volume of water concerned is small, may be admitted into a canal and absorbed in it; examples of inlets suitable for this purpose are illustrated on pages 229 and 230. But when the volume is too large to be treated in this manner, the discharge of the cross drainage must be passed, either (1) through the canal by inlets and escapes, or (2) over it by super-passages, or (3) under it by syphons, culverts, or aqueducts. The system to be adopted depends mainly on the relative levels of the beds of the canal and drainage, and partly on the relative cost of the different systems: when the bed of the drainage is at the same level as that of the canal or slightly above it, it is generally cheaper to pass the discharge through the canal by means of an inlet on one bank and an escape on the other, than to carry it under the canal in syphon. If the bed of the drainage is above that of the canal, a super-passage is generally cheaper, and more secure, than a syphon. If the bed of the drainage is below that of the canal, it is generally better—and, of course, essential if the canal is navigable—to carry the drainage under the canal, through a syphon or aqueduct, than to place the canal in syphon under the drainage.

In dealing with all questions of cross drainages, the first point which has to be considered is the maximum discharge which has to be carried across the canal. In Chapter IV., the question of maximum flow-off from catchments has been treated, and statistics have been given which help to determine the probable discharge from any given area; but it is better, when it is possible, to rely on gauged discharges of actual floods rather than on any estimate based on the area drained.

The Orissa Coast Canal, which is a canal for navigation only, in Bengal, crosses heavy drainages and spills, which attain to more than 40,000 cubic feet a second in some cases: it affords a good example of the manner in which such drainage may be passed through a canal by inlets and outlets (or escapes) in the banks when the drainages are broad and shallow.

The Plate on page 231 shows the system of construction which was employed; the length of the work was, of course, varied with the volume to be discharged: the particular case shown is one of a small drainage, and the outlet was designed so that the canal could be supplied through it from a tidal stream.

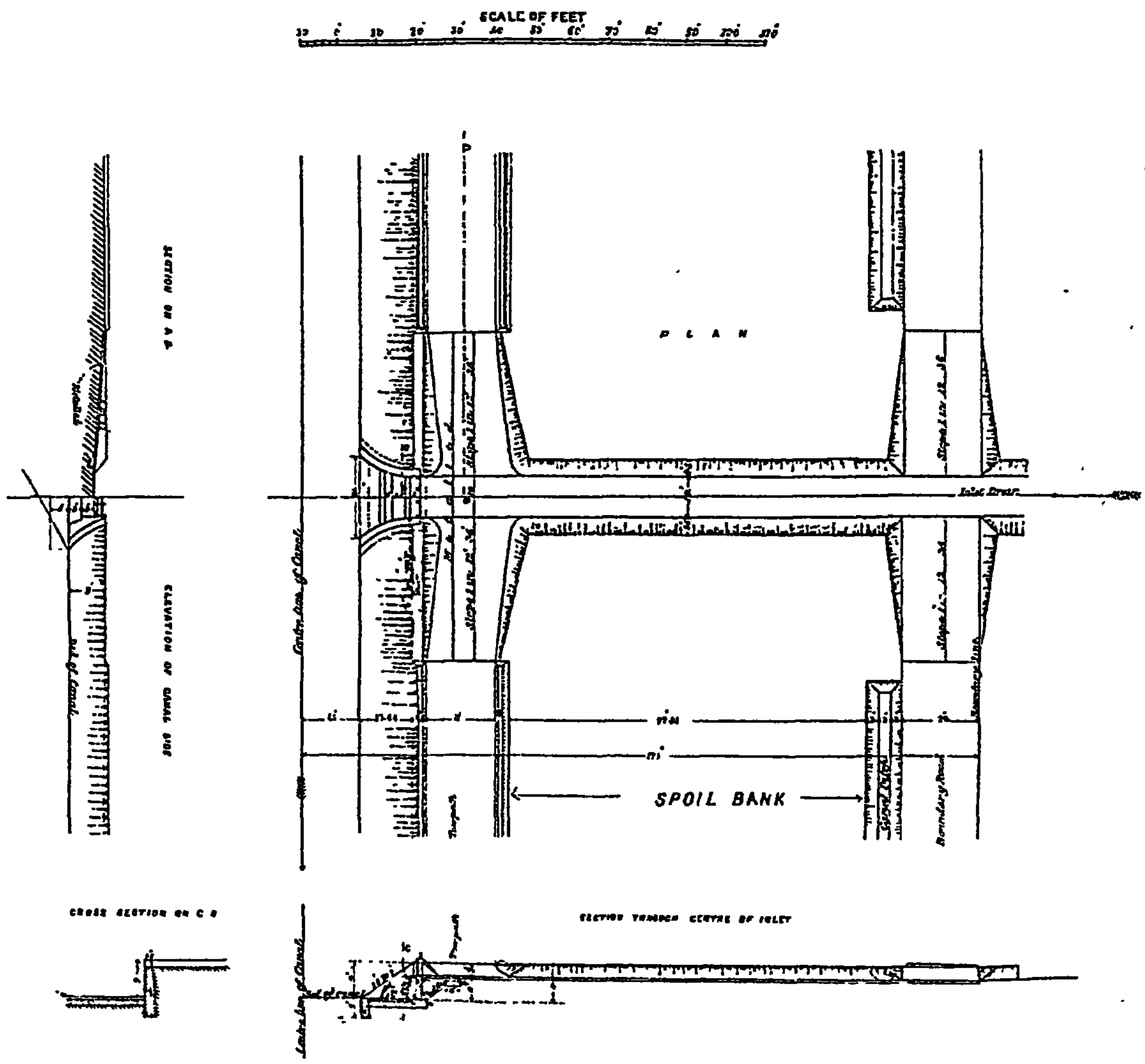
The Rutmoo torrent, which crosses the Ganges Canal at a point where the bed of the



DRAINS AND INLETS ON THE EDEN CANAL IN BENGAL.

torrent and that of the canal are at about the same level, carries some 30,000 cubic feet a second, and has a bed slope, near the canal, of over 8 feet a mile. There is an inlet and an escape opposite each other on either bank of the canal, and a regulating bridge in the canal itself below the crossing, so that, when there is a flood in the Rutmoo, the discharge of the canal can be regulated at will, and is not affected by the discharge of the torrent. The inlet and escape consist essentially of a floor at canal bed level with piers dividing the opening into

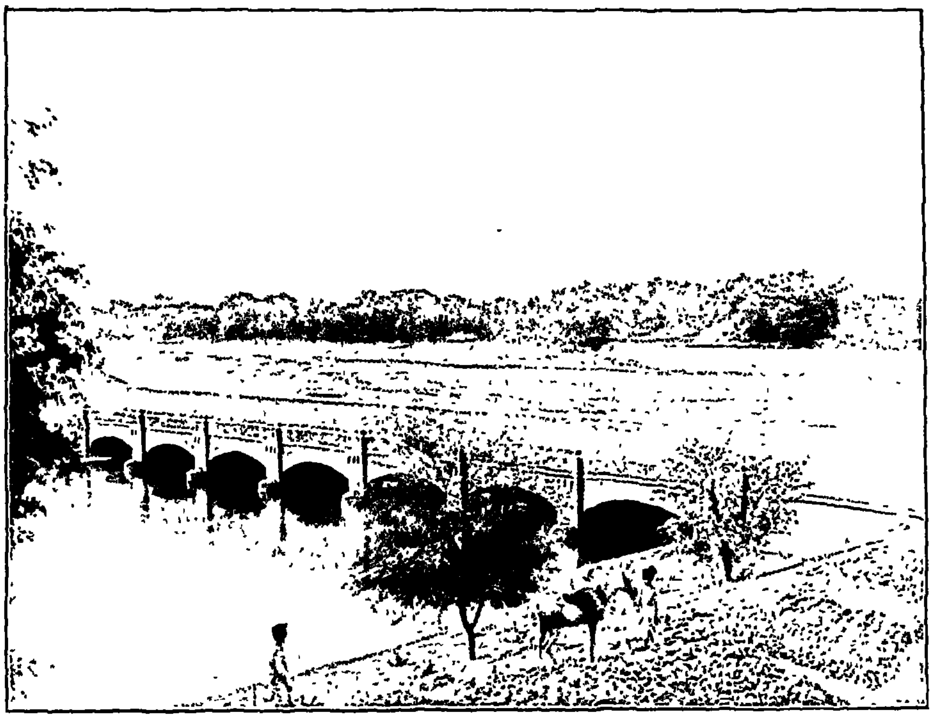
bays which can be closed by shutters. The intention originally was to close up the vents in the inlet to prevent the water standing up the bed of the Rutmoo, and arrangements were made for draining off any leakage; but in practice this is not done, but the canal water remains impounded in the depressed channel of the stream when there is no discharge in the torrent, so that the masonry inlet might have been omitted altogether. The outlet is fitted with falling gates, hinged at the lower edge, which can be let go easily when a sudden flood comes down



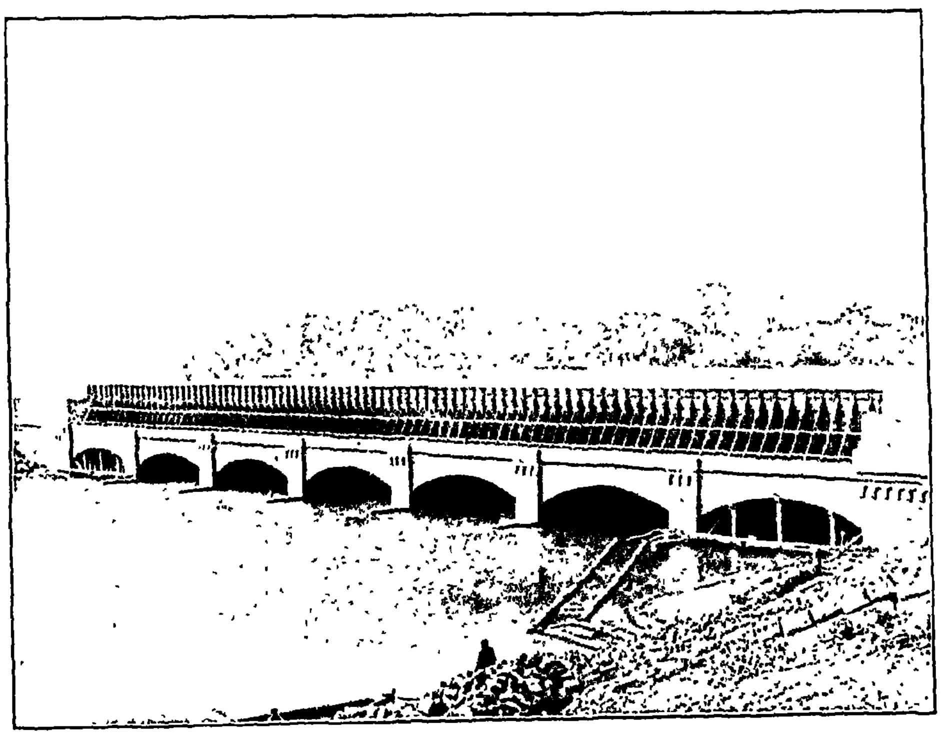
INLETS ON THE SIRHIND CANAL IN THE PUNJAB.

the Rutmoo, and there are grooves for "kurries," or horizontal baulks, in front of the falling gates. The fall of the bed of the torrent below the canal is rapid, and a retrogression of levels in the bed, which would have been dangerous to the canal, is checked by a series of five weirs, or bars of masonry, each having a drop of 4 or 5 feet, which are placed at intervals of 200 feet or so from each other. In several cases, streams which cross the Eastern and Western Jumna Canals are taken through the channels in a somewhat similar manner.

In these cases there is not infrequently some danger of the canal being blocked up by the detritus carried forward and deposited by these hill streams. The action of hill torrents in



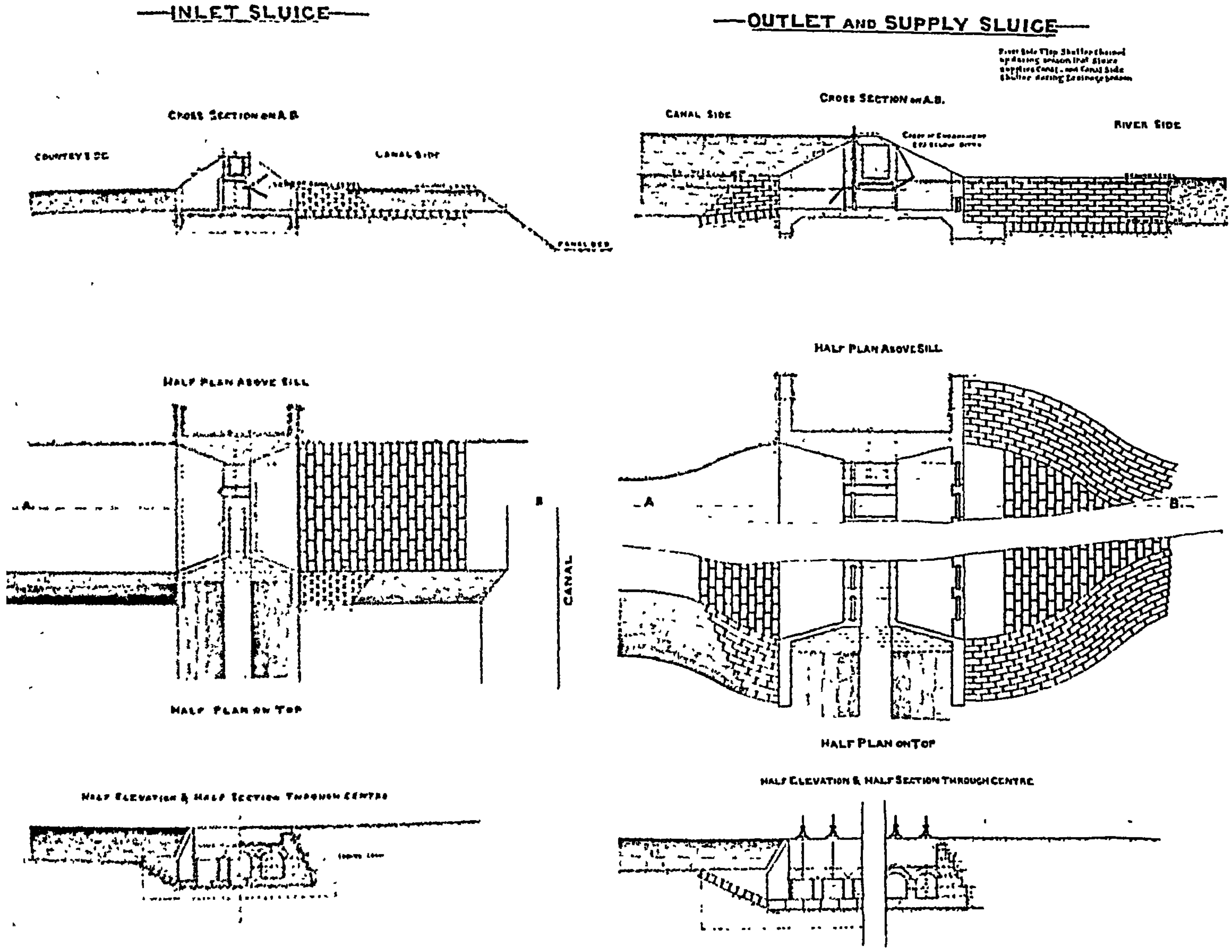
BUDKI SUPER-PASSAGE ON THE SIRHIND CANAL.



SISWAN SUPER-PASSAGE ON THE SIRHIND CANAL.

[To face page 230

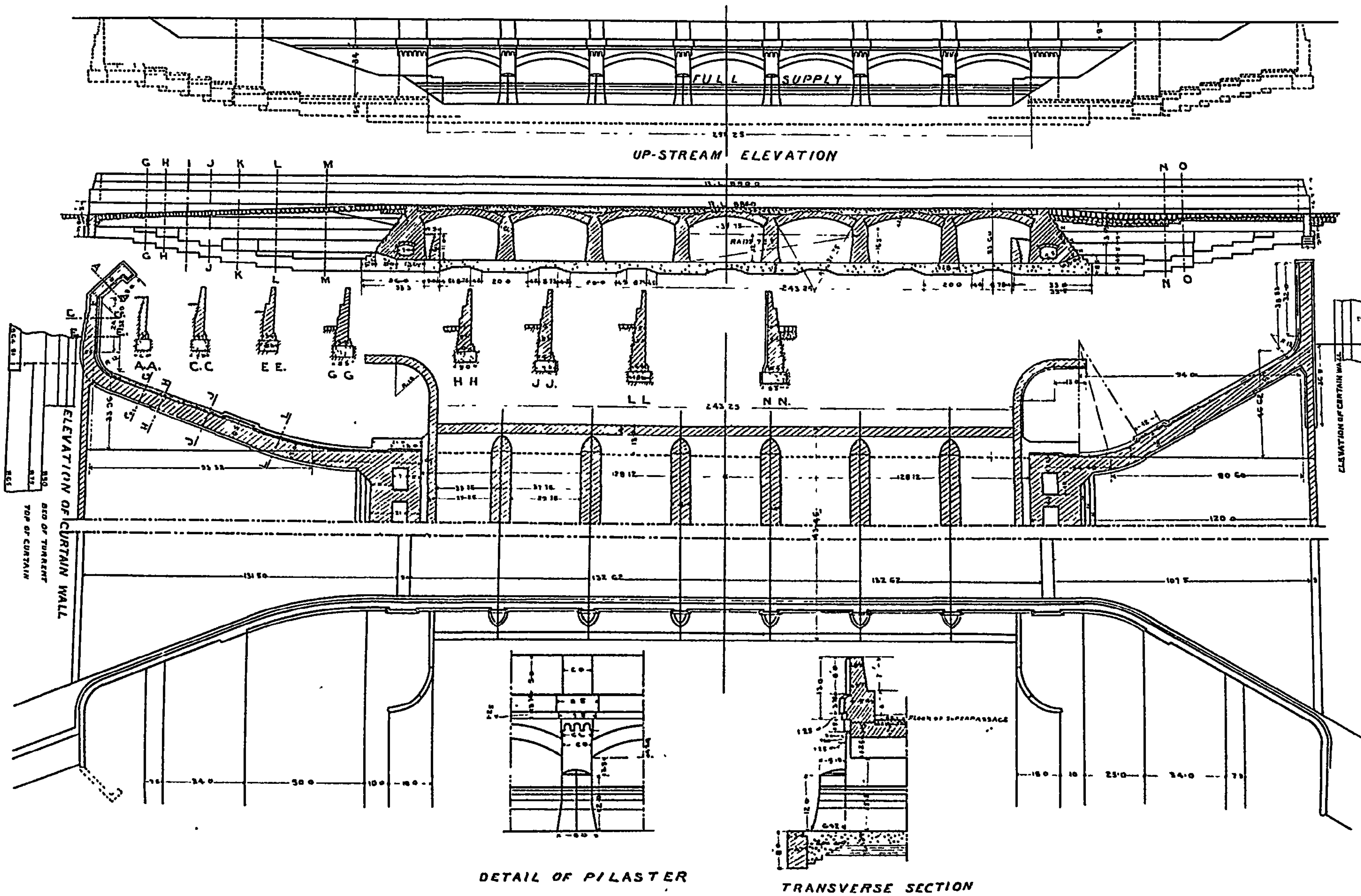
eroding one portion of their beds, and in raising other portions by pushing forward fan-like terraces of deposits, is well known,[1] and is very similar to the action of larger rivers in forming deltas at their junction with the sea. A torrent descends in a bed which, in the hills and near the foot of them, may have a fall as great as 40 feet or 60 feet in the mile; in this portion of its course it will be constantly eroding its bed by cutting back and increasing the slope until the action is stopped by rock; the velocity will be great, and the eroded matter, whether



Inlet, Outlet, and Supply Sluices on the Orissa Coast Canal.

boulders, shingle, sand, or mud, will be carried forward in the stream. Further from the hills the slope of the stream becomes reduced, and it will spread out over the plain and deposit fan-shaped layers of shingle or sand, which, in the course of years, block its passage, and compel it to take a course to the right or left of the one it has previously followed. A similar process goes on in this new course, and the country is raised gradually by a system of incremental deposits, which ultimately so seriously impede the discharge of the stream, that, on the occasion probably of an unusually heavy flood, it forces a passage through the ground it has itself raised,

[1] And is fully described in Chapter II. of Sir Proby Cautley's Book on the Ganges Canal.



BUDKI SUPER-PASSAGE ON THE SIRHIND CANAL.

and, cutting a channel through its own deposits, it carries forward the shingle and sand to the lower ground below, which it then attacks in the same manner. If it so happens that a canal is carried through the zone in which a torrent is raising the surrounding land, the deposits may seriously affect any work which may be constructed to pass the torrent across the canal. Such a case has occurred on the Ganges Canal, where the Puttri torrent has been carried over it in a super-passage. The crossing is about 6½ miles from the foot of the hills, where the slope of the stream is about 25 feet a mile; since the super-passage was built the bed of the stream has been raised, by the action just described, some 6 or 8 feet, so that the top of the side walls, which were 10 and 12 feet above the floor of the channel, are now only 5 and 6 feet above the silted bed, and the floods sometimes overtop them. In the case of the Rampoor super-passage—which is another torrent crossing the Ganges Canal—this difficulty has not occurred, for the work is so near the hills that the zone of deposit is beyond the canal. The floor of the super-passage is quite clear of all shingle or silt.

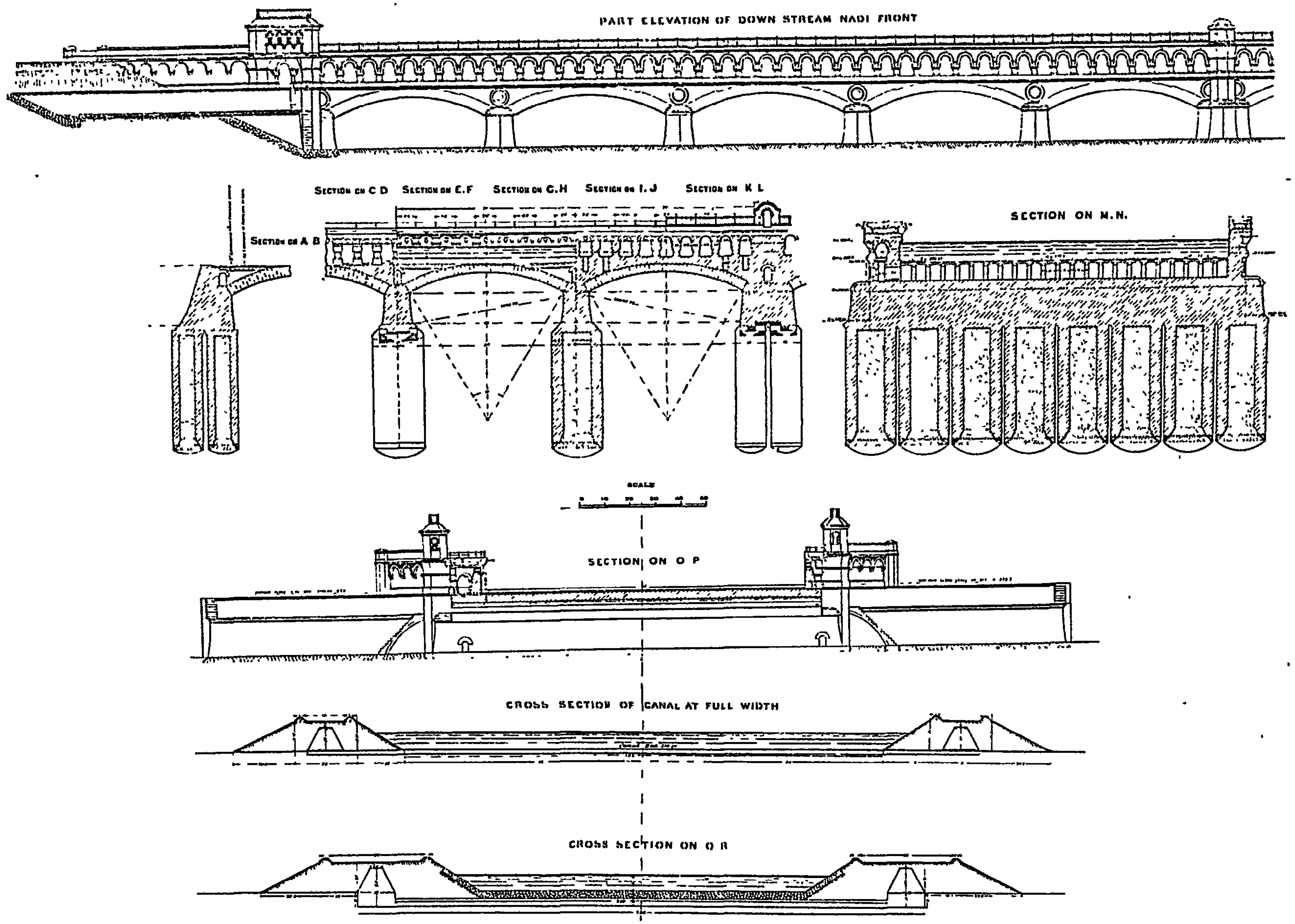
The Plate on page 232 shows the Budki super-passage which carries the joint floods of the Sugh and Budki torrents across the Sirhind Canal at a height of 24 feet above it. These torrents are estimated to carry the following discharges:—

Name of Torrent.	Drainage Area in Square Miles			Length of the Catchment Basins above the Canal in Miles.	Computed Flood Discharges.		
					By Observations on Floods in Cubic Feet per Second.	Deduced from Rainfall.	
	In the Hills.	In the Plains	Total.			Discharge in Cubic Feet per Second	Flow off Catchment in Inches per Hour.
Sugh	18	21	39	14	21,504	15,495	0·61
Budki	12	35	47	17	12,493	13,111	0·45
Total	30	56	86	—	33,997	28,606	0·515

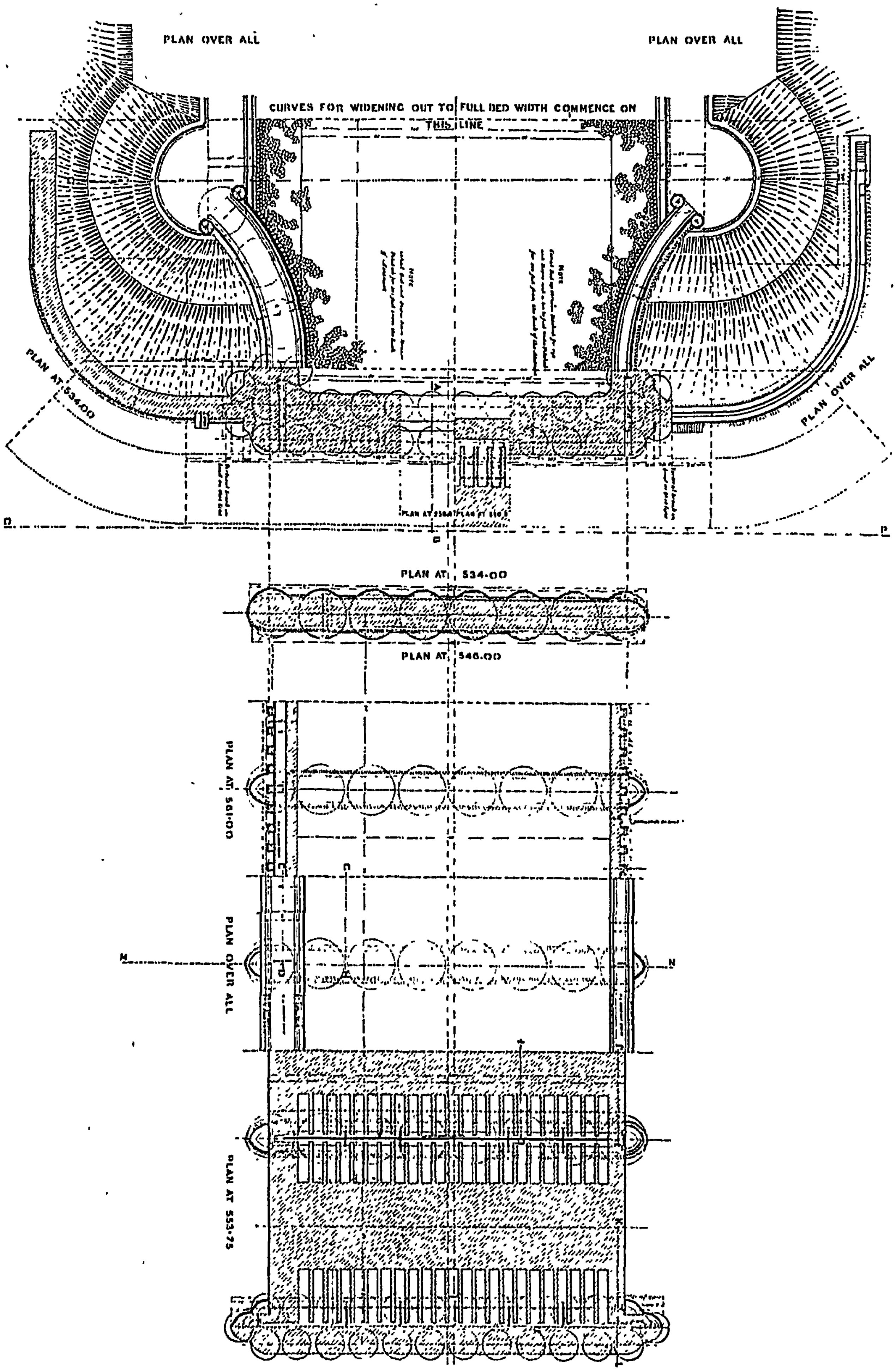
The super-passage was designed to carry 30,000 cubic feet per second only,[1] as it was considered that the discharge ascertained by observation on the surface slope and cross section of the flood, was in excess of the truth. The width of the super-passage between the parapets is 400 feet, and the depth, when carrying 30,000 cubic feet a second, is estimated to be 8·84 feet at the entrance, and 8·4 feet at the outfall. The channel leading to the super-passage consists of a central gullet with an inclination of 1 in 625, which is of sufficient width (540 feet) to carry ordinary floods, but the side banks of the channel are retired 110 feet on either side of this central gullet, so that, in great floods there is sufficient waterway to carry the maximum discharge within the limits of the levels fixed for the water surface.

The soil below the foundation of this work consisted of a layer of hard firm clay, about 8 feet thick, overlying sand, which covered a second stratum of blue clay. The concrete foundation, which is entirely boxed in with a curtain wall 8 feet deep below the canal bed, was designed to be 20 feet broad and 5 feet thick under the piers: this was sufficient to reduce the gross pressure on the base to less than two tons on the square foot, which was considered a suitable maximum in this case. In the neighbouring case of the Siswan super-passage,

[1] Report, dated March 6th, 1879, on the Budki Super-passage, by Mr. (Sir Thomas) Higham.



KALI NADI AQUEDUCT ON THE LOWER GANGES CANAL.



KALI NADI AQUEDUCT ON THE LOWER GANGES CANAL.

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which carries a torrent of 20,000 cubic feet a second over the same canal, the nature of the foundation was less favourable, as it consisted of a 10-foot layer of thick, tenacious black clay, overlying a fine blue sand of unknown depth, which was of the nature of a quicksand; being charged with water under a pressure of about 24 feet above the surface of the sand. In this case the super-passage—which is otherwise very similar in design to the Budki one—has inverts turned below the piers to distribute the pressure over the whole area underlying the work. The maximum pressure at the under side of the floor is a little more than one ton per square foot.

During the construction[1] of the Siswan super-passage frequent accidents occurred, which were mainly due to the great head of water which had to be controlled; the clay stratum was pierced in many places. Cracks appeared in the foundation before the work was completed, and numerous others appeared in the super-structure soon afterwards, especially in the down-stream parapet wall. In 1890 and 1891 it was found necessary to largely increase the waterway of the torrent over the canal, and the parapet walls were raised and thickened in a manner that increased the weight of them by 3¼ tons per foot run. In 1899 a big transverse crack appeared running right across the super-passage about 50 feet from the down-stream end, which was found to extend through the inverts. The down-stream end of the super-passage sank from 4 to 6 inches, and the down-stream parapet wall was thrown out of plumb. This was partly due, no doubt, to the weight of the parapet wall, but mainly to the movements of the fine sand in the foundations: springs blowing silt appeared when the canal was dry. In 1902 a line of sheet piles, tongued into each other, was driven right across the canal bed 75 feet from the down-stream face of the super-passage, with the object of preventing any underground movement of the sand, and eventually the floor of the work was extended to this point. The heavy parapet wall was also dismantled in 1904, and a light steel one with vertical frames was substituted. This is shown in the illustration opposite page 230.[2] In 1903 and 1904, during the closure of the canal, the cracks in the work were closed by "stock-ramming" with Portland cement, and super-inverts 13 feet long were laid just under the down-stream face of the super-passage. Buttresses are to be built, later on, on these inverts, against the down-stream ends of the piers. Over 200 barrels of cement were poured down the grouting pipes in one year. This has already done much good, and it is hoped that when the work is completed there will be no more movement in the foundation of this important super-passage. But it will probably be necessary to still further increase the length of the floor to prevent percolation under the work. Standpipes were erected in May, 1904, to test the head of water pressure on the floor: it was found to amount to 4·52 feet when the canal was dry. This is sufficient to cause a flow of water below the super-passage, and it is believed that the flow might be strong enough to carry with it the light sand which underlies the clay foundation.

Where it is necessary to carry the discharge of a torrent, river, or drainage under a canal, the nature of the work depends on the relative levels of the canal and the surface of the water to be passed across it. When the surface level of the latter is below the bed of the canal, an aqueduct is required, and the problem to be dealt with is very similar to that of a super-passage the only difference being that in an aqueduct the canal flows over the stream or drainage, and in a super-passage, the latter flows over the canal. The Solani aqueduct,[3] which carries the Ganges Canal over the Solani river by fifteen arches of 50 feet span, was the largest in India until the Kali Nadi aqueduct was constructed on the Lower Ganges Canal. The Solani river drains an area of about 216 square miles, and has a flood discharge of about 35,000 cubic feet a second. The extreme width of the foundation of the aqueduct is 252 feet, and the waterway of the

[1] Note by Mr. H. J. Johnston, C.I.E., Superintending Engineer, dated July 27th, 1904.

[2] See paper by Sir Hanbury Brown in Proc. Inst. of C.E., Vol. clviii, 1904.

[3] Which is fully described in Chapter IX. of the second volume of Sir Proby Cautley's "Report on the Ganges Canal."

aqueduct itself, which carries the canal discharge of about 6,500 cubic feet a second, is 172 feet broad; it is divided by a continuous wall along the centre, and piers fitted with grooves are built at each end, so that one half of the aqueduct can be closed for repairs. The parapet walls are 12 feet 9 inches high.

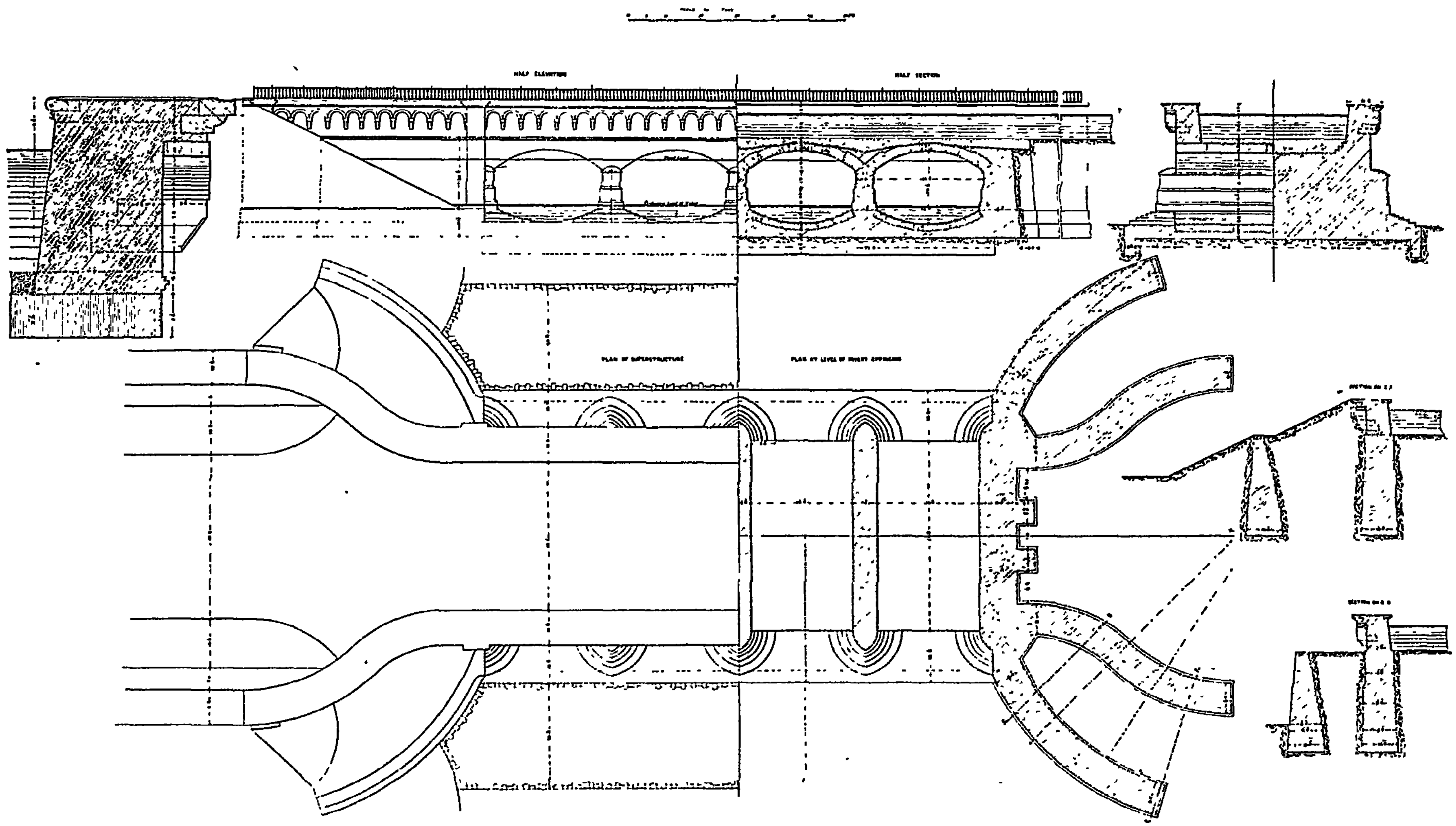
The Nadrai or Kali Nadi aqueduct, Plate on pages 234 and 235, which is referred to on page 51, carries the Lower Ganges Canal, which at this point has a maximum discharge of 4,100 cubic feet a second, over the Kali Nadi, which drains an area of 2,377 square miles, and has a maximum discharge of more than 130,000 cubic feet a second. The waterway provided has been calculated at 9·81 square feet per square mile of catchment, allowing for the sandy bed of the stream to be scoured out 10 feet deep by a maximum flood of 140,000 cubic feet per second, which would then pass through with a mean velocity of 6 feet per second. The arches would be entirely submerged by such a flood, but the afflux would not exceed 6 inches. A sunken floor, to be formed of concrete blocks 5 feet thick, was designed to be laid at a depth of 10 feet below the river bed, but this was not laid, as it was considered, when the work was under construction, that the clay substratum, which was found below the sand would resist the scour. There is, however, a special protective floor in both the end spans. The aqueduct has fifteen spans[1] of 60 feet each, divided by abutment piers into three sets of five spans each; the whole work is founded on wells sunk 50 feet below the bed of the stream. The pressure on the bases of these wells does not exceed 2½ tons on the square foot under the most unfavourable circumstances, and that on the bases of the abutment piers is only about two-thirds of that amount. The circular wells are 20 feet in diameter under the piers and left (canal) wings, 13 feet diameter under the river wings, and 12 feet diameter under the abutments, abutment piers, and right (canal) land wings. The river wing walls run back well beyond the ends of the land wings, to protect the flanks of the work. The main arches are 4·15 feet thick for one-third of their width at the centre, and 4·58 feet at the sides: the load on the main arch is lightened by spandril arches of 4 feet span, with piers 1·7 feet thick. There is one course of bricks laid flat in cement over the spandril arches, and the entire canal floor is covered with a layer of fine cement concrete, and the sides of the channel are plastered in cement in order to make them perfectly water-tight. The width of the channel across the aqueduct is only 130 feet, which causes a velocity of 4 feet a second at times of maximum supply: the bed and sides of the earthen channel, where it is contracted above and below the aqueduct, are strongly revetted with rubble to enable them to stand the velocity. There is a 12-foot roadway on one side of the aqueduct and a 6-foot bridle-path on the other. The parapets are carried on corbelling. In the embanked approaches, which extend across the valley in continuation of the aqueduct for a total length of 1¼ miles, the bed of the canal was formed of a layer of puddle 2 feet thick covered by 1 foot depth of soil. The banks, on each side, are also protected against percolation by vertical puddled cores 4 feet thick, rising from the level of the bed of the stream up to 2 feet below the top of the embankment. The total cost of the work was about 45 lakhs of rupees.

The Solani and Nadrai aqueducts[2] share between them the distinction of being the largest in the world; the following statistics concerning them may be interesting:—

	Solani.	Nadrai.
River waterway ...	13,000	21,600 square feet.
Canal waterway ...	1,600	1,040 " "
Canal discharge ...	6,780	4,100 cubic feet per second.
Arches and spans ...	15 of 50	15 of 60 feet.
Width between faces ...	195	148·7 feet.
Length	1,170	1,310 feet
Depth of foundations below river bed ...	19	52 "
Total height	56	88 "
Cost	32,87,000	44,57,000 rupees.
Time taken in building	7	4 years.

[1] Note by Colonel J. G. Forbes, R.E., Chief Engineer, N.-W. Provinces.

[2] Note by Mr. Devenish, Executive Engineer.



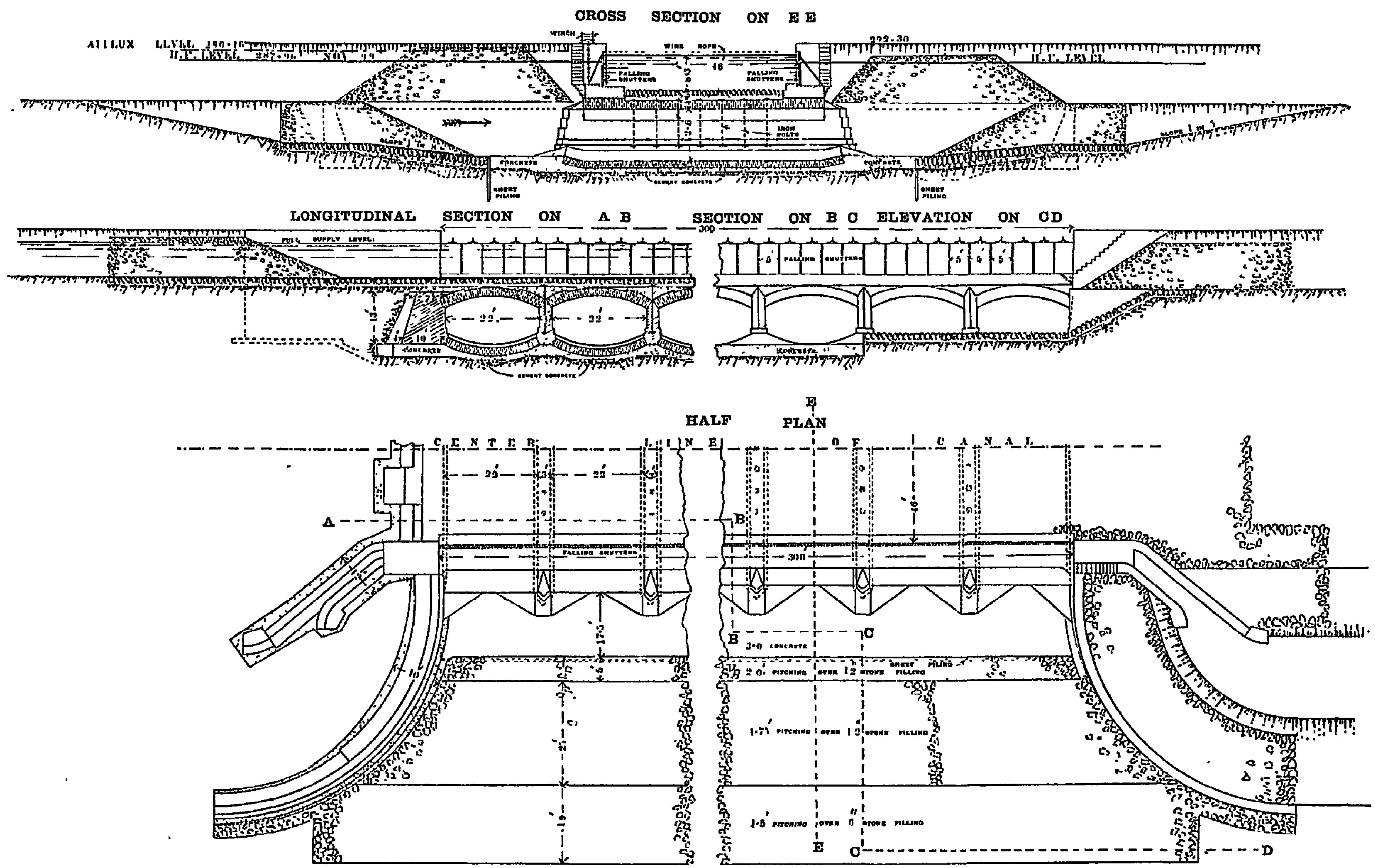
AQUEDUCT OVER THE THORA NULLAH, BUXAR CANAL.

The Plate on page 238 shows an aqueduct on the Sone Canal.

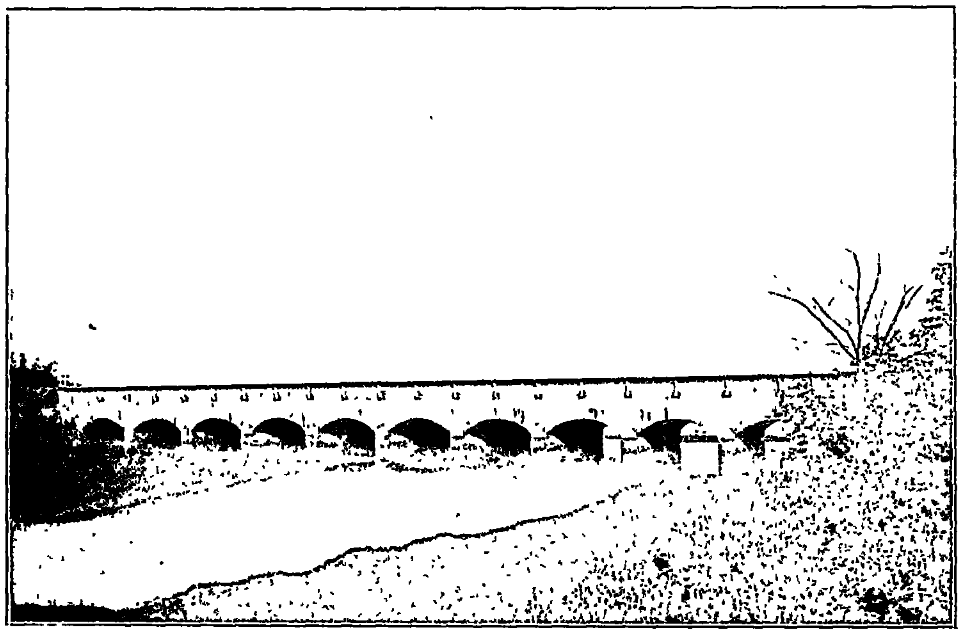
The Thapangaing aqueduct on the Mandalay Canal, in Burma, is an interesting work with some novel features. The Thapangaing nullah is a perennial stream which crosses the canal in the 7th mile. It is a hill torrent with a catchment area of about 172 square miles. The cold-weather discharge is insignificant, but it is subject to sudden and heavy floods in the monsoon season, which extends from May to November. It has often occurred in such cases that the engineers have, in the first instance, underestimated the maximum flood discharge. It occurred in this case. The original estimate for this aqueduct contemplated a maximum flood discharge of 5,347 cubic feet a second; a later calculation placed the figure at 17,760 cubic feet. The Inspector-General of Irrigation required a work to carry 24,000 cubic feet; and the work was commenced and partially built, on that basis, as an ordinary aqueduct with arched vents and masonry parapet walls. There were twelve spans of 22 feet in the design. While it was under construction the Thapangaing river rose, on November 1st, 1899, 20 feet in five hours, and the discharge of it was estimated to be 56,273 cubic feet a second, or 327 cubic feet per second per square mile. This is a very large discharge for a tract of 172 square miles, but the calculations, on which it was based, were certainly made with care. It was not possible to gauge the actual flood: the discharge was calculated afterwards on cross sections, flood levels, and surface slopes. The rainfall which caused the flood was 7·37 inches in seven days at Sedaw, 10·43 inches at Mandalay, and 13·35 inches at Maymyo; on one day (November 1st) the fall was 3·70, 5·60, and 4·38 respectively at the three places. This is nothing very extraordinary for India. The river has a narrow and tortuous channel only 20 to 30 feet wide through a valley densely covered with tall grass, trees, bamboos and shrubs, which must greatly impede the flow of the water. The whole catchment overlies rock which outcrops in many places, and it has a steep slope. The hills are everywhere covered with jungle. It seems almost impossible that such a region, 172 square miles in area, can have given a maximum discharge of 327 cubic feet per second per square mile. The calculations were made by taking the cross section of the deep channel and the side portions separately. N. in Kutter's formula was taken as 0·03 in the channel itself and 0·04 in the side portions. From the side portions a depth of 2 feet was deducted to allow for the obstruction caused by grass and trees. It would seem probable that the discharge in the side portions, which really determined the heavy discharge, was considerably exaggerated. However, it is not well to be too certain in such a case, and the example is quoted here as an interesting one for engineers who have to deal with flood discharges in hilly tracts.

This calculated discharge of 56,273 cubic feet per second was so much in excess of that allowed in the project that the design had to be entirely altered. It was ultimately decided to adhere to the sanctioned plan as far as possible, but to substitute wooden shutters for the masonry parapet walls so that a discharge of 60,000 cubic feet per second would pass partly under and partly over the work. The work was recommenced in December, 1899, and completed by the close of 1901 at a cost of Rs. 3,84,471.

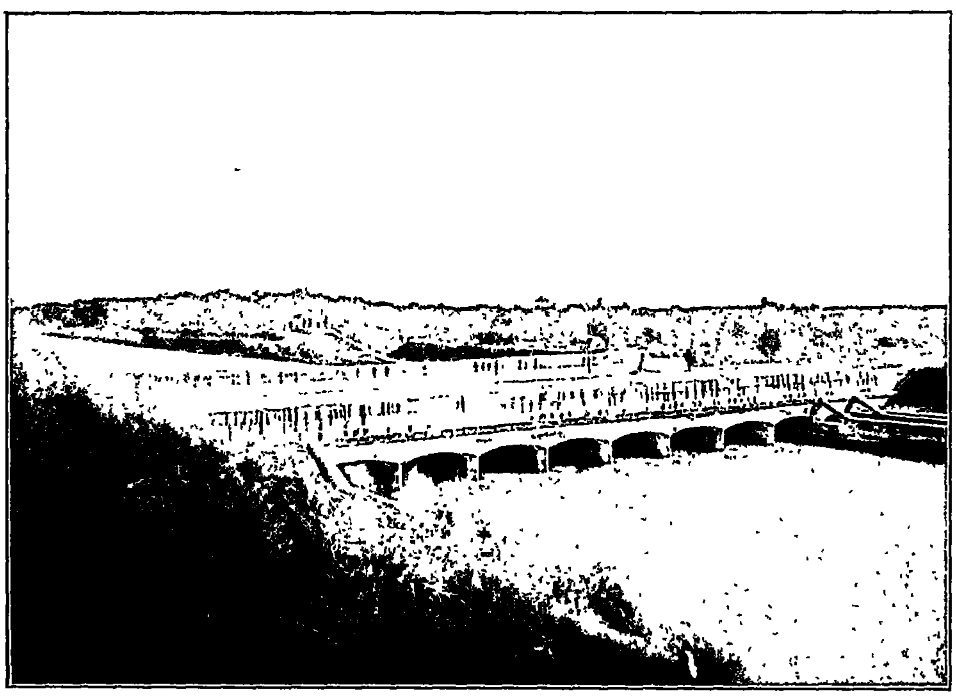
The design of the work is indicated by the Plate on the next page, and it is only necessary to explain the wooden shutters. A length of 300 feet of each of the side walls of the aqueduct is formed of falling shutters. There are sixty pairs of shutters, spaced 46 feet apart for the canal waterway, each shutter being 4 feet 11¾ inches long by 7 feet high. Each pair of shutters is connected across the canal at the upper end by a wire rope attached to the triangular brackets fixed on the top of the shutters, and is hinged at lower end. The hinges consist of cast-iron trunnions secured to the shutter by an iron strap, which is bolted along its whole length. The trunnions rest on saddles secured by straps to short rolled-iron beams built



THAPANGAING AQUEDUCT ON THE MANDALAY CANAL



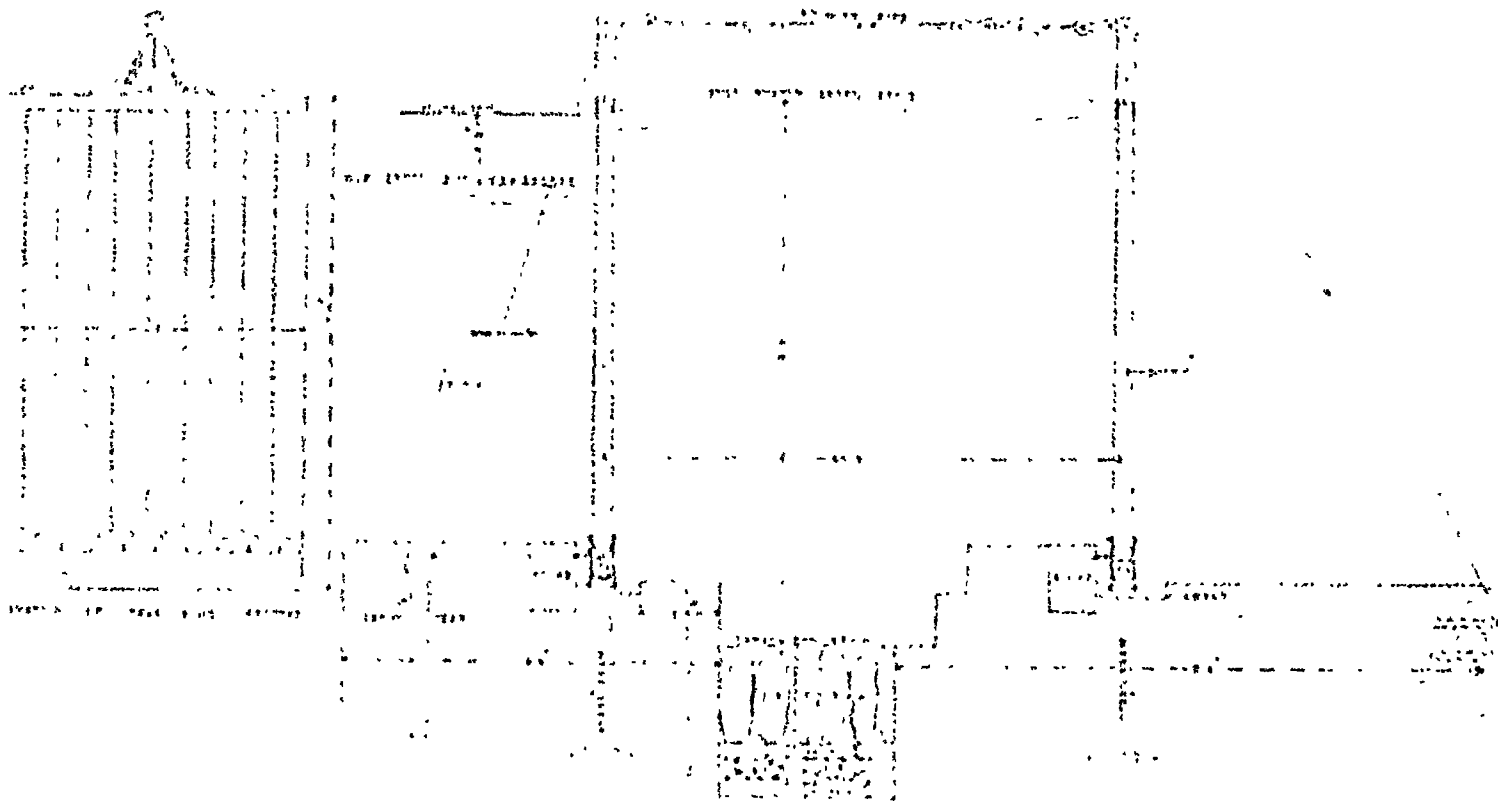
KERAI AQUEDUCT, MIDNAPORE CANAL



RANIPUR SUPER PASSAGE, GANGES CANAL.

[To face page 240

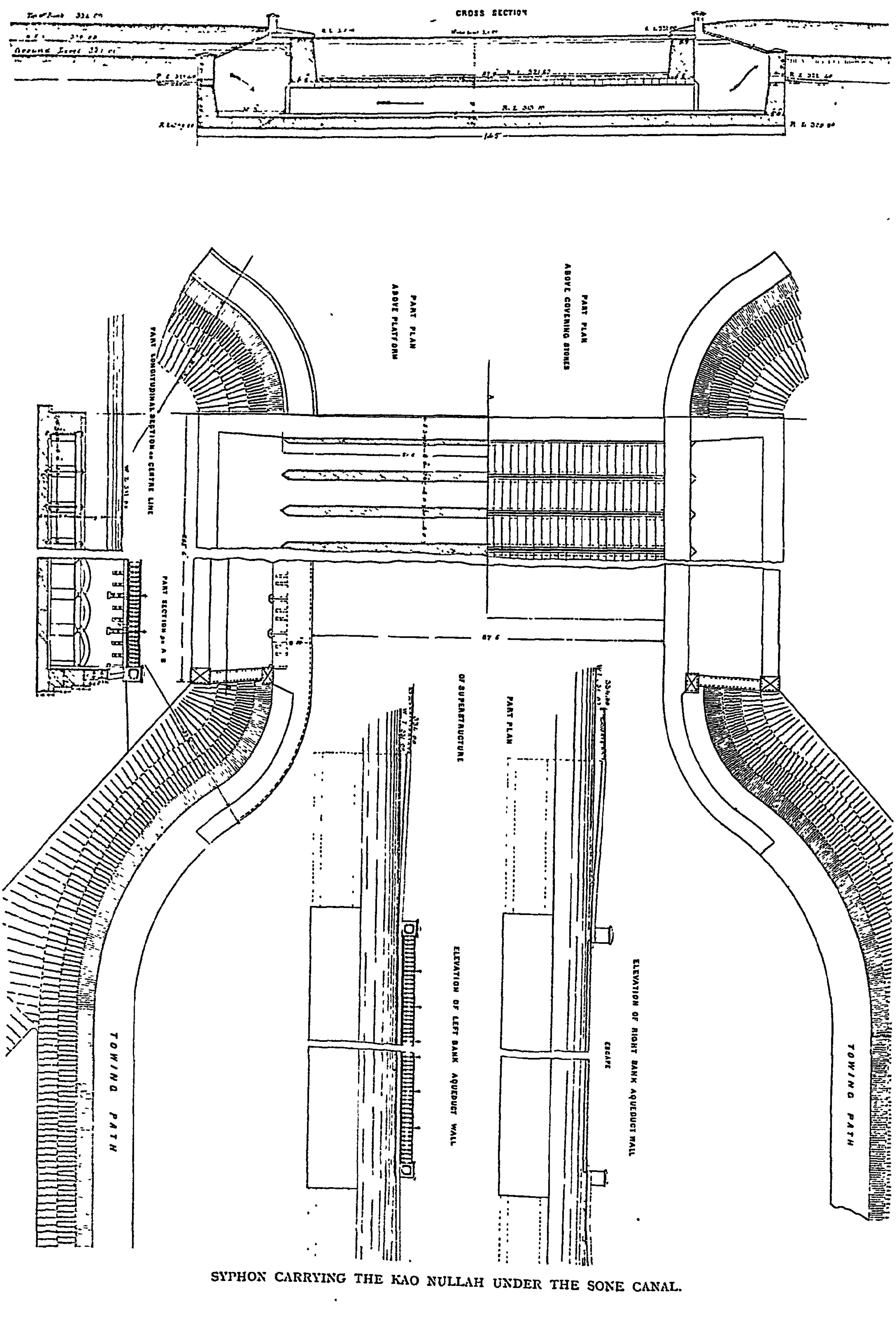
vertically into the masonry exactly below the ends of the shutters. The shutters are also held erect and prevented from falling towards the canal by tension rods. These are hinged at their upper ends to the brackets on the shutter. The lower end of the up-stream tension rod engages by a hook with the let-go gearing, and the lower end of the down-stream tension rod is hinged to the side wall of the aqueduct. Leakage between and below the shutters is prevented by a staunching arrangement of 1-inch strips of rubber, which are pressed, over the vertical joint on the canal side by strips of wood fixed to the shutters by small springs and screws, and on the lower end of the shutters by hoop iron. Experience has shown that the rubber strips act very well in the horizontal joints, but that tarred oakum is best in the vertical ones.



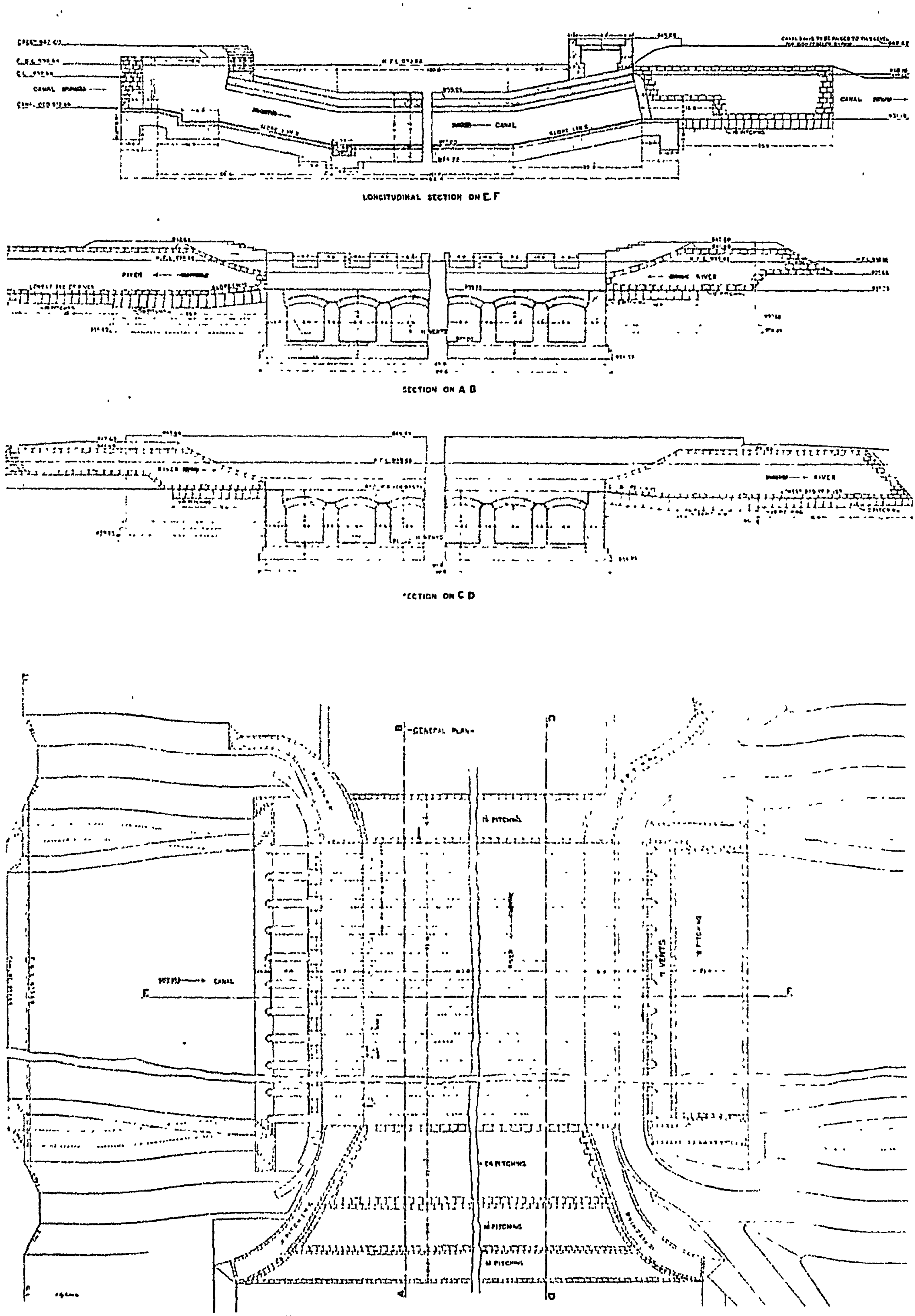
FALLING THE SHUTTERS OF THE THAPANGAING AQUEDUCT.

The let-go gear is built into the masonry sill opposite the centre of each up-stream shutter, and consists of a lever and trigger arrangement. The lever is actuated by one of a series of lead balls fastened on a wire rope, while the trigger secures the hooked end of the upper tension rod. The wire rope of the let-go gear winds on to the drum of a winch fastened on the top of the wing wall, and, passing over two pulleys, traverses the whole length up-stream of the shutters. It ends in a suspended counter-weight. Lead balls are fastened at intervals on the wire rope to actuate the let-go gear, so that as the wire rope is wound up on the winch the lead balls come into play one after the other.

There is telephonic communication between the aqueduct and the head-works, as well as down the canal. In the event of a rising flood the canal head is closed as soon as a certain level is reached, the needles are put into a regulator below the aqueduct, and, when the flood has reached another fixed level, the winch is manned and as many shutters as are considered necessary are lowered. It is only necessary to lower the shutters occasionally, as all ordinary



SYPHON CARRYING THE KAO NULLAH UNDER THE SONE CANAL.



BURRA BUBSA SYPHON ON THE TREBENI CANAL.

floods pass through the vents below the aqueduct. Up to the end of 1904, the shutters had only been used on two occasions, when they acted well. It is necessary to keep 3 feet of water in the canal at the time of release as a cushion for the falling shutters.

When the surface of the water in a drainage or stream is approximately at the same level as that of the canal, or when it is above the canal surface, it is necessary to pass the drainage (if it must go below the canal) by a syphon aqueduct. The Plate on page 242 shows a work of this kind which carries the flood of the Kao Nullah under the Main Western Canal in the Sone system in Bengal. The nullah, which drains an area of 57 square miles, of which the greater part is in hilly ground, is subject to sudden floods, and the discharge was estimated to be equal to a flow-off of 6 inches in twenty-four hours, or 161 cubic feet per second per square mile; but experience has shown that the discharge is not as great. This work, and most others of this class, is subject to the disadvantage that the syphon is liable to be filled up by detritus washed into it during a flood. The result of this may be disastrous. An accident of this kind occurred on the Kistna Canals in Madras,[1] where a syphon aqueduct, somewhat similar to the one just mentioned, became filled up by detritus and was entirely swept away: the water of the drainage breaking across the canal. In the case of the Kao syphon the accumulations in it have to be partially cleared out every year.

The Plate on page 243 shows the case of a canal passing in syphon under a river. The Trebeni Canal in Bengal crosses the drainage of a large tract of country at the foot of the Himalayas, in the Chumparun district. In some cases the drainage is allowed to flow into the canal, in others the canal is carried by aqueducts over the drainage channel, and in six cases it dives in syphon under the drainage. The case shown in the Plate is where the canal, carrying a discharge of nearly 3,000 cubic feet a second, passes under the Burra Bubsa nullah, which has a flood discharge of about 5,000 cubic feet a second.

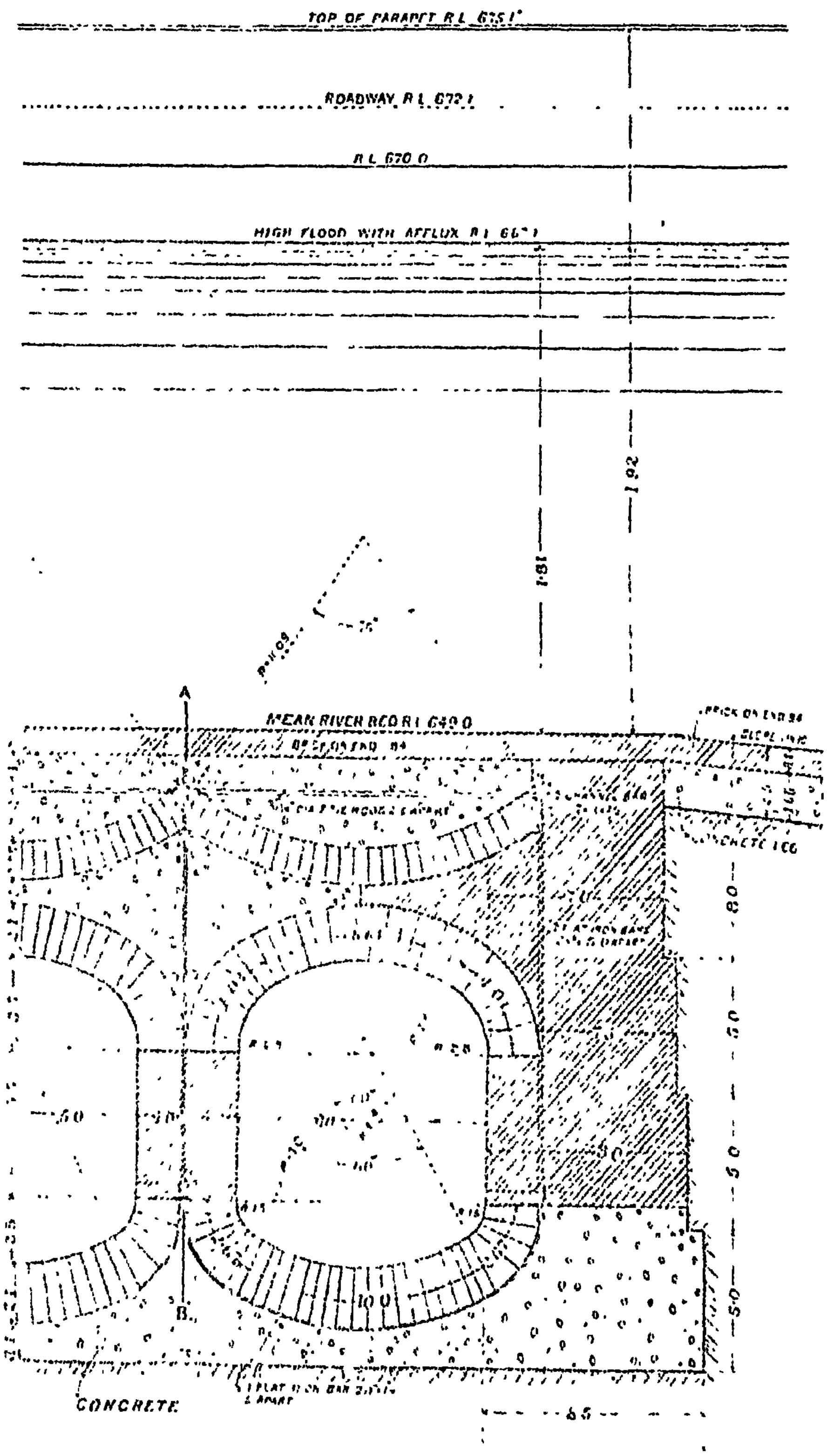
In all the works of this class it is necessary to consider the upward pressure on the covering of the syphon vents due to the head upon them under the most unfavourable conditions: these conditions occur when there is no water in the upper channel. It may be that the canal will never be dry at the time when a flood occurs in the drainage, but it is usually better to provide for such a case. In the Kao syphon the cover stones of the vents are anchored down to the foundation by wrought-iron bolts.

In 1899 a large syphon in Egypt which carried one canal under another was wrecked in consequence of the excessive upward pressure. The syphon consisted of four barrels, 10 feet wide by $5\frac{1}{2}$ feet high: the piers were $3\frac{1}{4}$ feet thick, and the arches and covering made together about $6\frac{1}{2}$ feet of solid masonry over the top of the vents. At the time when the syphon failed there was only $3\frac{1}{2}$ feet of water in the upper canal, but the one passing under the syphon was full, and there was a head of over 20 feet of water tending to lift the crown of the syphon. The difference between the downward pressure of the masonry, plus the water in the upper canal, and the upward pressure of the water on the soffit of the arches, was about 300 lbs. on the square foot. This placed the mortar joints of the masonry in tension to the extent of about 500 to 600 lbs. on the square foot. The joints were unequal to the strain, and the whole crown of the syphon, which was a solid piece of masonry about 385 feet by 65 feet by $6\frac{1}{2}$ feet, was slightly lifted upwards and cracked in several pieces. The water, from the canal which was in syphon, flowed up into the one above. The mortar joints ought to have been able to stand the tension, and there is no doubt that many syphons do stand secure, which are only stable in consequence of the tensile strength of the masonry. But it is rarely desirable to trust to that strength to any great extent.

[1] Note by Inspector-General of Irrigation, page 23, Sone Canal Selection. Bengal, 1890.

In the case of the syphon which is to be constructed to carry the new Lower Bari Doab Canal under the Ravi river in the Punjab,[1] the section of the vents is to be as shown in this sketch.

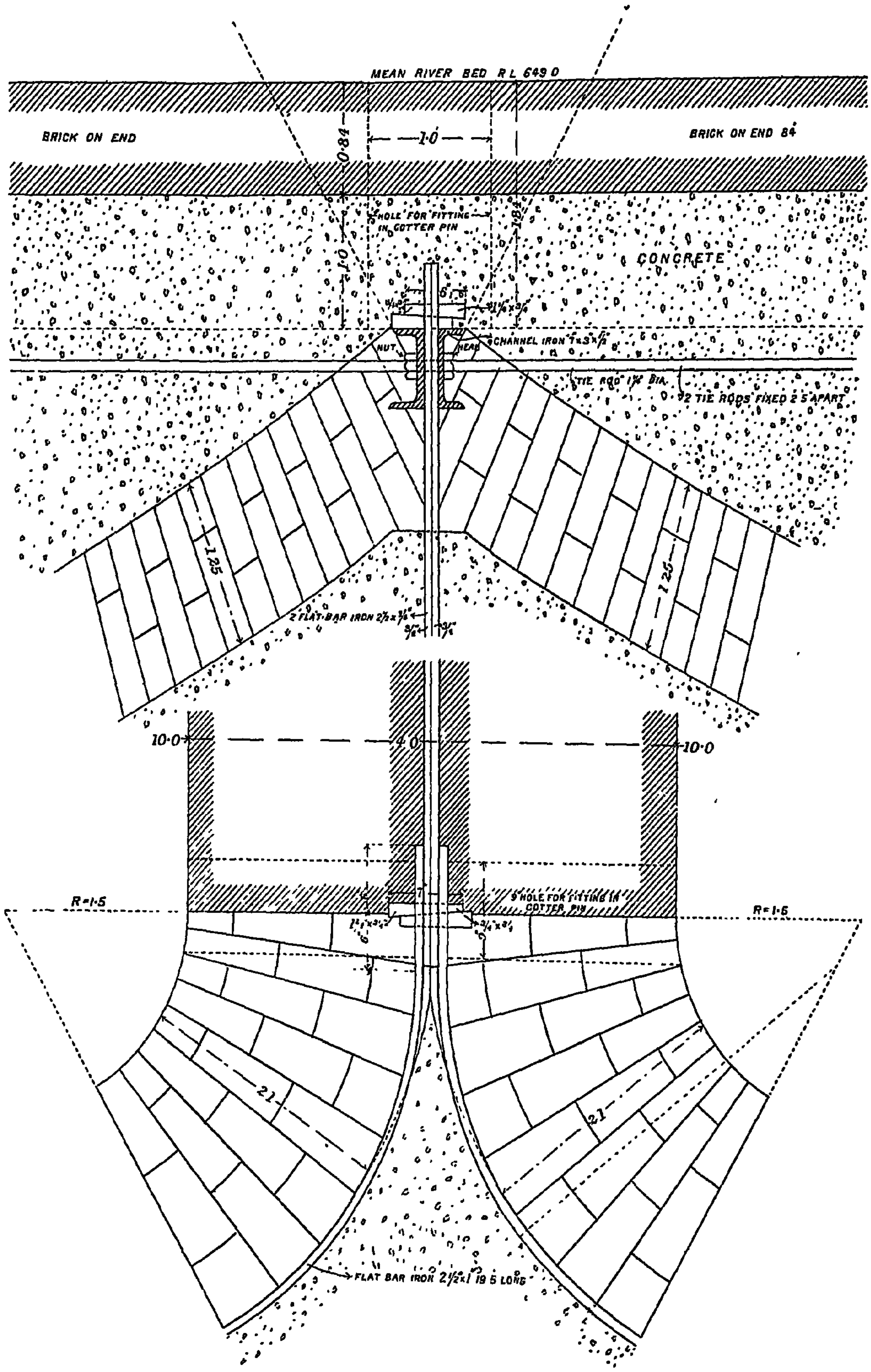
The full supply level in the canal above this syphon is 668·75, and the soffit of the arch of the syphon is 641·0. When the river is at its lowest there will be a head of 27 feet on the soffit. The ordinary rough rule is to make the thickness of the crown of a syphon $\frac{4}{10}$ths of the head on the upstream side. To do this, in the case of the Ravi syphon, would have necessitated very deep foundations and heavy pumping. It has, consequently, been decided to construct the vents as shown on this and the next page.



Section of the Barrels of the Ravi Syphon.

It is claimed for this arrangement that all parts of the iron-work can be renewed except the straps under the inverts. But it would appear to be quite as necessary to renew these straps as to renew any other part of the iron-work. It is stated that even if the invert straps become completely unserviceable, the mortar at the base of the piers would only be subjected to a tension of 5 lbs. on the square inch, and that ordinary *kunkur* lime mortar can be relied

[1] Note by Mr. J. Benton, C.I.E., Chief Engineer, Punjab.



DETAILS OF TIES IN THE BARRELS OF THE RAVI SYPHON.

upon to stand a higher strain. This is quite true: but the example which has just been quoted is a warning that syphons may be wrecked when the tension on the mortar joints is less than 5 lbs. on the square inch. The Ravi syphon will leave eight vents, $11\frac{1}{2}$ feet by 10 feet, and it will carry nearly 6,500 cubic feet per second under the river. The syphon will be nearly 1,400 feet in length between the trough walls. There is a drop in the water level of 4 feet through the syphon, which seems more than ample. The Ravi, when in flood, will discharge about 200,000 cubic feet per second over it. The piers are made rather unusually thick to add to the weight which will, by means of the vertical ties, resist the upward pressure. The inverts in the backing of the arches assist in conveying the pressure to the ties and tend to prevent the work failing at the crown of the arches by transverse stress.

Syphons made of steel tubes encased in concrete are in use in the Swat River Canal in the Punjab, and are proposed to be used in several cases on the new Upper Jhelum and Upper Chenab Canals. Those in use in the Swat River Canal[1] are tubes of mild steel $\frac{3}{16}$ inch thick and 3·75 feet in diameter. The units are made in 25-feet lengths with planed angle-iron flanges, which are bolted together in the syphon at site. The tube is made of sufficient length to place the foundations of the brickwork approach and exit chambers well in soil, and is given a slope from the sides towards the centre. In the centre of the syphon there is a small standpipe with a removable cover, so that the tube can be pumped out if necessary. The steel tubes are laid in a timbered trench filled with concrete, with a minimum thickness of 18 inches. The maximum pressure on the tube is that due to about 40 feet head, but the tubes were all tested to a pressure of 60 lbs. on the square inch. Expansion joints were provided, but the value of these is doubtful. These syphons, carrying about 100 cubic feet per second cost from Rs. 90 to Rs. 115 per foot run of tube. It is interesting to note that the discharges through these syphons was obtained with considerably less head than had been allowed. They were designed with a head of 4 feet, and the velocity was calculated by the formula

$$V = 8{\cdot}025 \sqrt{\frac{h\,d}{(1 + f_0)\,d + 4 f l}}$$

where h = the head; d = the diameter of the tube; l = length of the tube; f_0 = 0·505; and f = 0·00511. But the velocity of $8\frac{1}{2}$ feet per second which was required was actually obtained with a head of about $2\frac{1}{2}$ feet, and not 4 feet. A series of experiments were made which showed that the friction co-efficient f in the formula

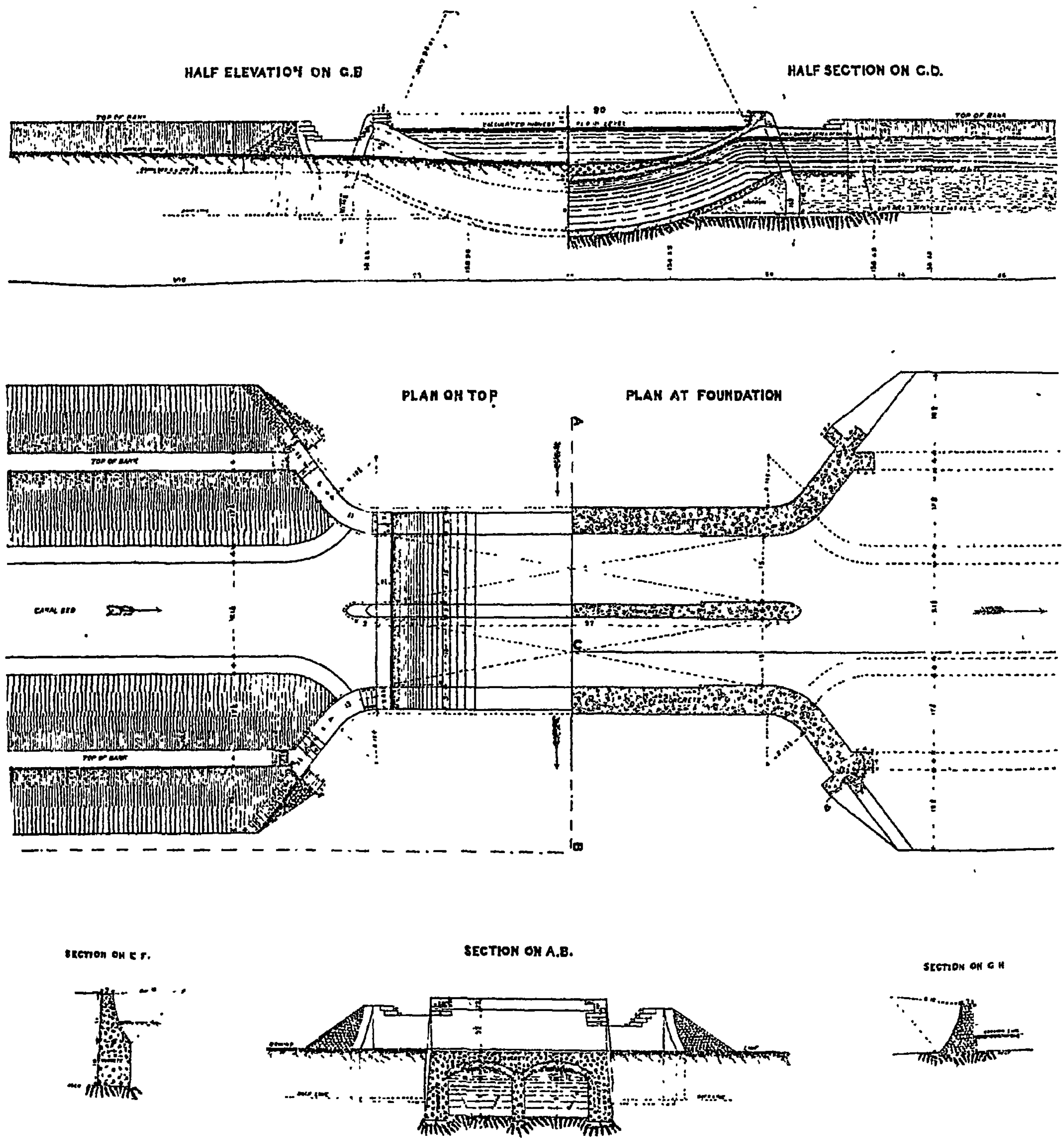
$$h f = \frac{v^2}{2g} \times \frac{4 f l}{d}$$

was ·00332, and not 0·0051, as the formula, on which the syphons were designed, had assumed.

It is claimed for this class of syphon that the steel tube will, in any case, last many years, and will be greatly preserved by the concrete casing; and that, during those years, the concrete will have attained such a strength that, even if the steel tube is entirely ineffective, the concrete pipe will resist the pressure. In the particular case of the Swat River Canal syphons the tensile stress on the concrete would ultimately be 22 lbs. per square inch. Good concrete should stand that stress. The difficulty, of course, is to ensure that every part of the concrete tube, and especially the parts where there is junction between concrete and masonry, is really good concrete. One weak spot would ruin the syphon if the steel tube were gone.

The Plate on page 248 shows a case in which a canal is carried in syphon under a

[1] Note dated July 25th, 1904, by Mr. J. T. Farrant, Superintending Engineer.

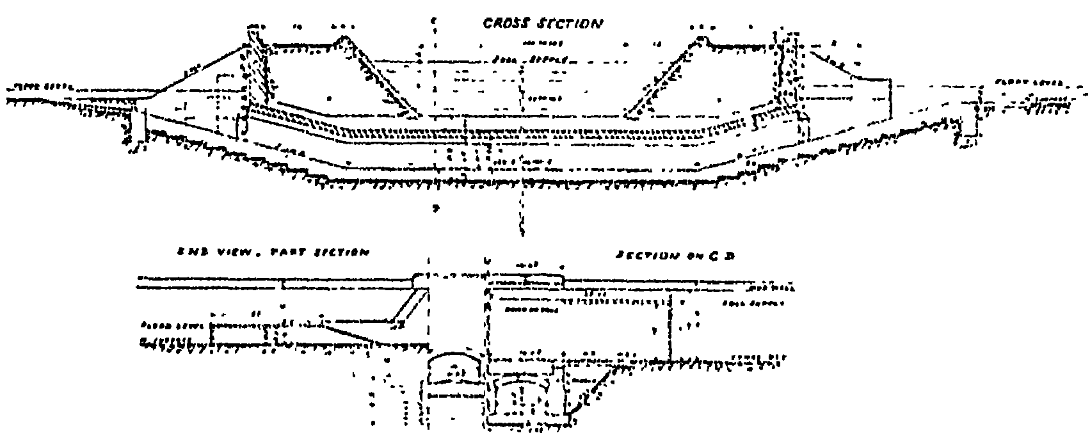


SUPER-PASSAGE ON THE NIRA CANAL, BOMBAY.

drainage. The Nira Canal syphon is peculiar: several of the kind have been constructed on the canal: the barrel of the syphon acts as an arch, and so utilises the weight of the abutments to resist the upward pressure of the canal. In these syphons there is rarely any water in the drainage crossing over the canal.

As a matter of economy it is, of course, advantageous to restrict the waterway of a syphon as much as possible, and it is also often desirable to do the same thing in order that a high velocity may prevent silt from being deposited in the barrels.

The capacity of the barrels of a syphon aqueduct is usually designed so that the maximum discharge can be passed at a velocity varying from 5 feet to 8 feet a second, provided that the circumstances permit of a sufficient head being placed on the syphon to generate such a velocity. In syphons with a vertical drop, such as that in the Plate on page 242, which was designed for a velocity of rather over 8 feet a second, the flow of the water approaching the syphon is checked by the vertical drop, and it is necessary to allow ample head to generate the required velocity in the syphon. In most cases a head of at least 30 inches would be required to generate an 8-feet velocity, and it is often difficult to obtain this without going to consider-

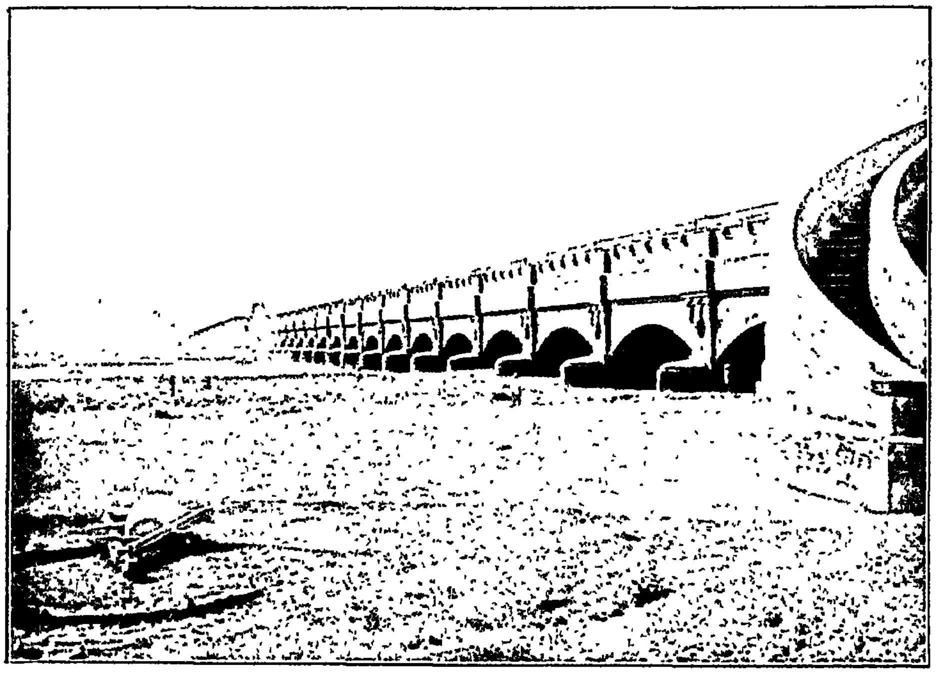


Typical Section of Syphons on the Chenab Canal, Punjab.

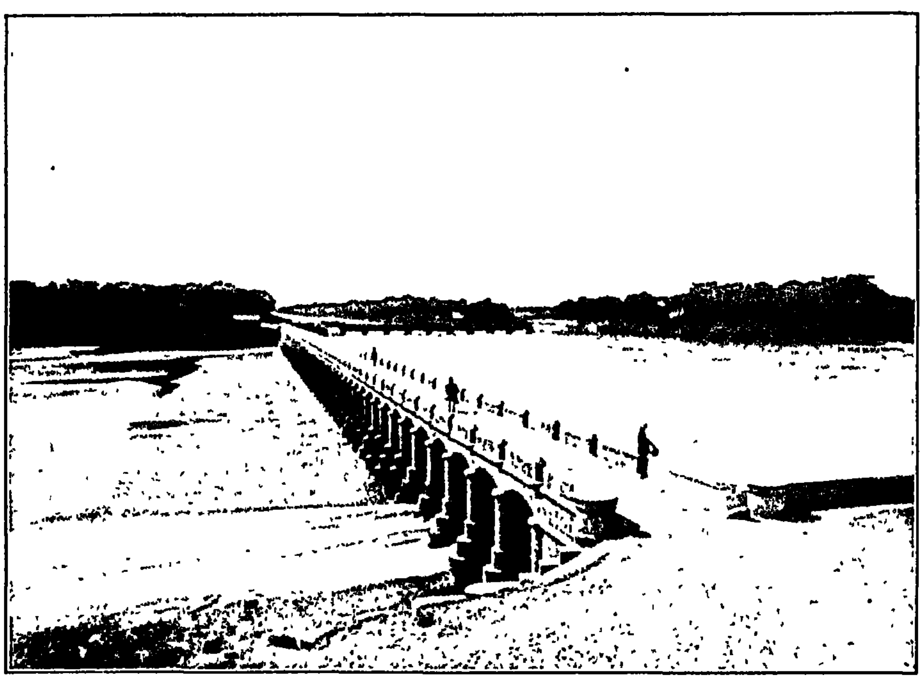
able expense, either in embanking the channel above the syphon or in excavating it below it; and in flat shallow drainages it may be impossible to do either. In the latter case there is no alternative but to increase the waterway of the barrels to such a point that they will be capable of carrying the discharge with the velocity due to the head which can be obtained. In estimating what that head will be, it is necessary to consider the discharging capacity of the channel below the syphon (if there be any defined channel) at different levels, and to compare these levels with those that will obtain in the upper channel when it is carrying corresponding quantities, and to inquire whether the difference between the two is in all cases sufficient to generate a velocity in the syphon which will pass the discharges through the waterway. At first sight it would appear that the water on the up-stream side would always accumulate above the syphon until a sufficient head was obtained to pass the discharge (assuming, of course, that the barrels were proportioned to a reasonable velocity). But in very flat drainages, such as have frequently to be dealt with on smaller canals and distributaries, it is often not practicable, for one thing, to permit of much heading-up, either from fear of damage to crops or houses, or for other reasons, and it will generally be found that, even when such heading-up is feasible, the rise in level on the down-stream side, due to the increased discharge, will so far counterbalance the rise on the up-stream side that it is not practicable to obtain a head sufficient to generate a velocity which will greatly exceed that of the water above the syphon. In such a

case the syphon has to be designed with far greater waterway than is necessary when dealing with a stream or drainage where there is a comparatively rapid slope and good outfall. In all cases of shallow drainages of slight surface slope, shallow and wide vents are preferable to narrow ones of the same waterway, in order that a wide entrance and exit over the lip of the syphon may be obtained for the water entering and leaving it. The sketch given on page 249 shows typical sections of the syphons which are being constructed on the Chenab Canal in the Punjab, which are very suitable for cases of this kind.

It must be remembered that in those cases where the drainage water is headed-up by a syphon, and there can be, of course, no overfall over the lip, the velocity over the lip into the well is necessarily no greater than the velocity of approach of the water in the drainage; in such a case the width of the lip must be determined by the maximum depth permissible, and the probable velocity of approach of the water; the width, in shallow drainages, will necessarily bear a larger proportion to the depth, and it is convenient that the vents should do the same. These considerations are not infrequently overlooked, and syphons are constructed with deep narrow vents and narrow entrances, in which the discharge is really determined by the discharge over the lip until the water on the up-stream side has headed-up to an extent which seriously floods the country or breaches the canal or distributary concerned.



Solani Aqueduct on the Ganges Canal.



Level Crossing at Dhanauri on the Ganges Canal.

[To face page 250.

CHAPTER XIV.

NAVIGATION, LOCKS.

Canals for Navigation only—Silting in Tidal Canals—Canals for both Irrigation and Navigation—Velocity of Flow in Canals for Navigation—Combined System of Irrigation and Navigation not Financially Successful—Navigation in India Generally—Navigable Rivers in Bengal—Relative Position of Lock and Weir—Cracking and Failure of Lock Walls—Apjohn's Theory of Settlement of Foundations in the Deltaic Soil of the Ganges—Pressures on Lock Walls—More Recent Designs adopted in Bengal—Equality of Pressure on Foundations desirable during Construction—Width of base of Lock Walls—Lock Gates and their Fittings.

THERE are three large canal systems in India which have been constructed solely for the purpose of navigation; these are the Circular and Eastern Canal and the Orissa Coast Canal (including the Tidal Canal) in Bengal,[1] and the Buckingham Canal in Madras. These systems are not used in any way for irrigation, and could not be so used, as the water in them is generally brackish. The canals are in immediate contact with the tidal creeks and rivers connected with the Bay of Bengal; indeed, the greater portion of the Circular and Eastern Canal, which connects Calcutta and Barrisaul in Eastern Bengal, consists of natural tidal channels which have been artificially improved, and which are maintained in a fairly efficient state in order to bear to Calcutta the products of the eastern and northern districts. The portion of the Orissa Coast Canal which is called the Tidal Canal was opened for traffic in 1869: it connects the Hoogly River with the Russulpore river by two tidal ranges. The Orissa Coast Canal proper, which is a continuation of the Tidal Canal, was opened for traffic throughout in September, 1887; it consists of three ranges connecting the Russulpore River with the Matai river in Orissa. The united system is a line of navigable canal which opens inland water communication between Calcutta and Orissa. The Buckingham Canal in Madras, which has some features in common with the Orissa Coast Canal, is also a coast line. It was undertaken primarily as a protective work after the famine of 1877—78, in order to connect the Godavery and Kistna deltas with the southern districts of the province. Of these three navigable systems, the Calcutta and Eastern Canal, which was in partial operation at the end of the last century, paid 5 and 6 per cent. on its capital outlay for many years. During the last ten years, however, the capital has been largely increased by improvements, and the financial results have fallen off, the net revenue now being only between 2 and 3 per cent. on the capital. The other canals are not financially successful. The statement on the next page gives some statistics concerning them.

The Calcutta and Eastern Canal is in some ways a remarkable work; it runs through the upper margin of the Sunderbun forests, where the land is generally below the very highest flood level, but has been reclaimed by embankments and is generally cultivated. A little nearer the Bay of Bengal the vast area of swampy land which forms the Sunderbuns is covered with dense maiden forest. The canal runs generally east and west, while the various channels, or "gongs" as they are locally called, which are connected with the Bay of Bengal, run generally north and south. These "gongs" are all tidal, up to, and in most cases a considerable distance

[1] The Tidal Canal appears separately in the Government statistical returns, as it was constructed from borrowed funds, and the Orissa Coast Canal was not. But these two really form one and the same line of navigation.

beyond, the canal itself, so that the general ebb and flow of the tide is more or less at right angles to the line of the canal. The main channels, however, are linked together by an intricate system of cross streams, which intersect the muddy swamps of the Sunderbuns in all directions, so that it is always possible to find a way from one "gong" to another in a direction

CAPITAL COST AND REVENUE DERIVED FROM THE LARGE NAVIGATION SYSTEMS.

Canal.	Length.	Capital outlay, direct and indirect, to end of 1901—1902	In the year 1901—1902.		
			Gross Revenue	Working expenses.	Net Revenue.
Bengal :—	Miles.	Rs	Rs.	Rs.	Rs.
Circular and Eastern Canal	737	68,04,619	3,85,385	2,65,049	1,20,336
Orissa Coast Canal (including the Tidal Canal)	132	70,94,534	95,571	85,548	10,023
Madras :—					
Buckingham Canal...	262	89,80,440	69,120	98,039	—28,919

which is more or less east and west. The canal has, in fact, utilised a connecting system of cross channels between the main "gongs" to a large extent, but in some cases artificial channels have been made. In many of these connecting channels a great difficulty has arisen owing to the tides meeting in them. The tide makes up the main "gongs" on either side of a connecting channel at the same time, and enters the east mouth and the west mouth of the canal channel simultaneously; the result is that the in-flowing tides meet at some point in the channel, and at that point there is no flow. The waters are heavily charged with silt, which is deposited very rapidly where the velocity of the flow is checked; consequently the canal silts badly at these meeting-points, and heavy expenditure in silt clearance is involved. There are, however, some of these cross channels which maintain a good waterway, especially under these two conditions :—

1. When, near the centre of the channel, there is connection with a *bheel* into which the tide flows and ebbs. The *bheel*, in this case, acts as a flushing reservoir, and maintains a flow of such a quantity of water past the centre of the channel as is sufficient to maintain a certain section.

2. When, owing to circumstances which it is most difficult to explain, the action of the tides in the large rivers is such that the channel in question becomes what the natives call *chowbatta* (four ebbs). This phenomenon is simply this :—In the twenty-four hours there are four instead of two ebbs, and four instead of two floods, or, to speak more correctly, the first portion of every tide (whether flood or ebb) flows in one direction and the second portion in the opposite direction. This action maintains a good channel, because the flow past the centre is constantly maintained.

The first system fails when the *bheel* silts up, or is reclaimed; the second only fails, when, owing to change in the tides of the large rivers, the *chowbatta* tides cease.

Out of the twenty-two large canal systems in Madras and the three Upper Provinces of India, which were primarily constructed for irrigation, eleven are also adapted, in certain portions of their channels, for navigation also. None of the canals in Bombay or Sind have

been constructed so as to be available for navigation, although small boats are sometimes used on parts of them. The mileage of irrigation canals which are navigable also is shown in the following statement. It has been maintained that it is desirable, if not necessary, to make the

Province.	Mileage of Irrigation Canals.	Mileage which is Navigable.
Bengal	719	495 (*a*)
United Provinces	1,483	537 (*b*)
Punjab	4,482	432 (*c*)
Madras	3,300	990 (*d*)

(*a*) The Orissa, Sone, and Midnapore Canals
(*b*) The Ganges, Lower Ganges, and Agra Canals
(*c*) The Western Jumna and Sirhind Canals.
(*d*) The Godavery, Kistna, and Kurnool Canals.

trunk lines of an irrigation system navigable, in order that an easy and cheap means of carriage may be available for exporting the surplus grains and other products which irrigation produces; it has been further argued that the expense of the additional work necessary is not large, while the convenience to the people and to the officers in charge of the canals is very great. It is by no means easy to estimate correctly the difference in cost between an irrigation canal of a given capacity, and one of the same capacity which is suitable for navigation; the difference is by no means represented by the cost of the locks which have to be added at the canal falls.

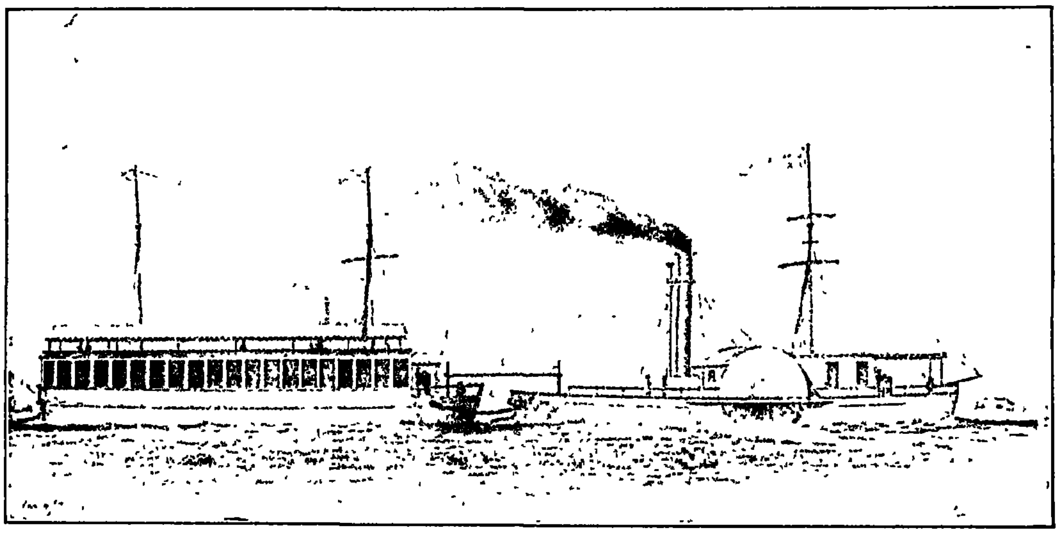
There are several other causes which increase the cost. In the first place it may be necessary to restrict the velocity of the water below that which the soil will stand, for a velocity of more than 2 feet a second will perceptibly check the traffic, and this necessitates a larger channel and more frequent falls in the canal bed. In Madras, indeed, a velocity of 1·50 to 1·75 feet per second is considered to be the highest allowable under ordinary circumstances in a canal which is used for navigation. The reduction of the velocity may be very prejudicial to the canal, as it may cause heavy silt deposits. Then, as it is often necessary to impound the water in canal reaches at times of low discharge in the canal, it then becomes necessary to increase the height of the banks and of the masonry works near the end of each reach; and again, a navigable canal cannot be reduced in width in accordance with the discharge required for irrigation, so it is often necessary to make the canal in its lower reaches much wider than is required for the purposes of irrigation only: and further, as frequent locks are to be avoided, in consequence of the impediment they offer to traffic, the reaches are lengthened as much as possible in a navigable canal, with the result that the volume of earthwork both above and below the locks is greatly in excess of that which would be necessary in a channel designed for irrigation only. The height of all bridges has to be increased, with the consequent expense of long approaches to them. A certain quantity of water is consumed in passing the boats through locks, which is consequently lost for irrigation if the canal finally tails into a navigable river; this is a disadvantage which may be of some moment when the supply in the hot weather is scanty and very valuable for sugar-cane crops.

It cannot be said that the combination of navigation with irrigation has been successful in India; the traffic has always proved to be far less than the projectors of the works anticipated, and the revenue derived from tolls, except in Bengal, is insufficient—or but rarely sufficient—

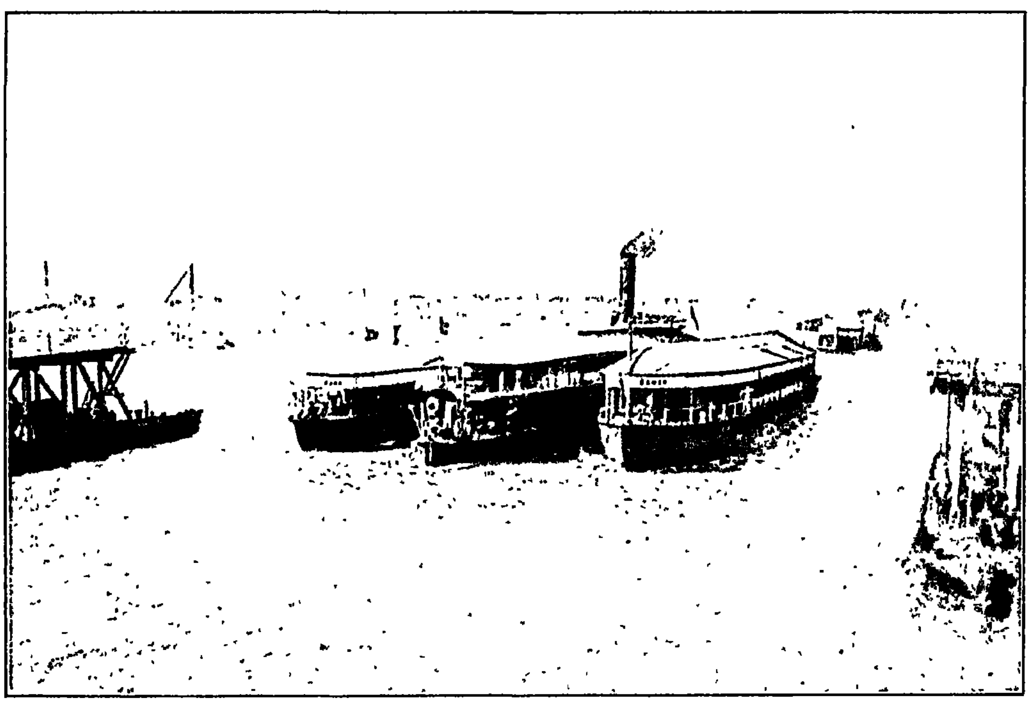
to cover the charges for establishment and maintenance alone, and gives no balance to cover interest on the capital cost of the works rendered necessary by navigation. When the system of making canals, primarily designed for irrigation, suitable for navigation also was first promulgated, great results were anticipated. Thus, Sir Arthur Cotton, writing in 1854,[1] of the Ganges Canal which was then under construction, wrote, "as a work of communication, too, there can be no question but that it will be of incalculable value. Such a magnificent canal . . . passing through a most populous and fertile country . . . will, if I mistake not, be the most important work yet executed or commenced in India," and he made a calculation tending to show that the navigation of this canal would lead to an economy in carriage of a very large sum annually. The amount of goods, however, carried on the Ganges Canal is very small, and tolls received are insufficient to cover the expenditure incurred on account of navigation. The canals in which navigation has been most successfully combined with irrigation are the Godavery system in Madras and the Orissa and Midnapore systems in Bengal. On these, as well as on the Sone Canals in Bengal, regular steamers are plying for traffic. One of the chief reasons, no doubt why water-carriage has not been generally successful in India is because canals primarily designed for irrigation do not connect centres of trade, but run on lines suitable for irrigating the land; another reason of the small receipts is probably to be found in the fact that in a highly cultivated district large numbers of draught cattle are required for ploughing, which, at odd times, are available for carting the surplus crops to market at a nominal cost to the owners.

As a matter of fact, little attention is given to any works in India for improving internal navigation. In this respect, indeed, India only follows the lead of England, where, unfortunately, the extensive system of navigable canals has sunk into a very inefficient condition, and nothing is done to improve them. In other countries this is not the case. On the continent of Europe, in Egypt, in the United States and in Canada, the Governments make themselves responsible, to a large extent, for the maintenance and extension of navigable waterways. In France, most noticeably, the State is constantly extending the navigable waterways, both on the rivers and by navigable canals. The State bears, almost entirely, the cost both of original construction and of maintenance. The water channels in France are, with few exceptions, entirely free of tolls. The results are striking. The water-borne traffic in France increases more rapidly than that on the railways. Germany has made great improvements in her internal waterways at the cost of the State, and charges very small tolls. Egypt used to charge tolls, not only on the canals, but on the Nile itself; but now these channels are all free of toll. In the United States and Canada all the open waterways and some of the canals are controlled by the State. The United States Government charges no tolls, although very large sums are expended on improvements. For instance, the American Government has spent about £400,000 recently on the Alleghany and Monongahela rivers. The latter has been canalised by locks for 130 miles above Pittsburgh, and enormous quantities of coal are carried down it, free of tolls, to the iron-works there. In the United States, in Germany, and in France, it is estimated that the ton-mileage of goods carried in steamers and boats is about one-third of the ton-mileage on the railways. The view which appears to find acceptance both in Europe and America is that the railways do not, ultimately, suffer from the competition of the canals and waterways. Indeed, in America, the view is expressed that, "paradoxical[2] as it seems, waterways are not only the most powerful possible regulators of railway rates, but are also the most powerful possible promoters of the prosperity of railways with which they compete."

[1] "Public Works in India," by Lieut.-Colonel Cotton, Madras, 1854, page 114.
[2] "The Effect of Navigable Inland Waterways on Railway Transportation," by Mr. S. A. Thomson.



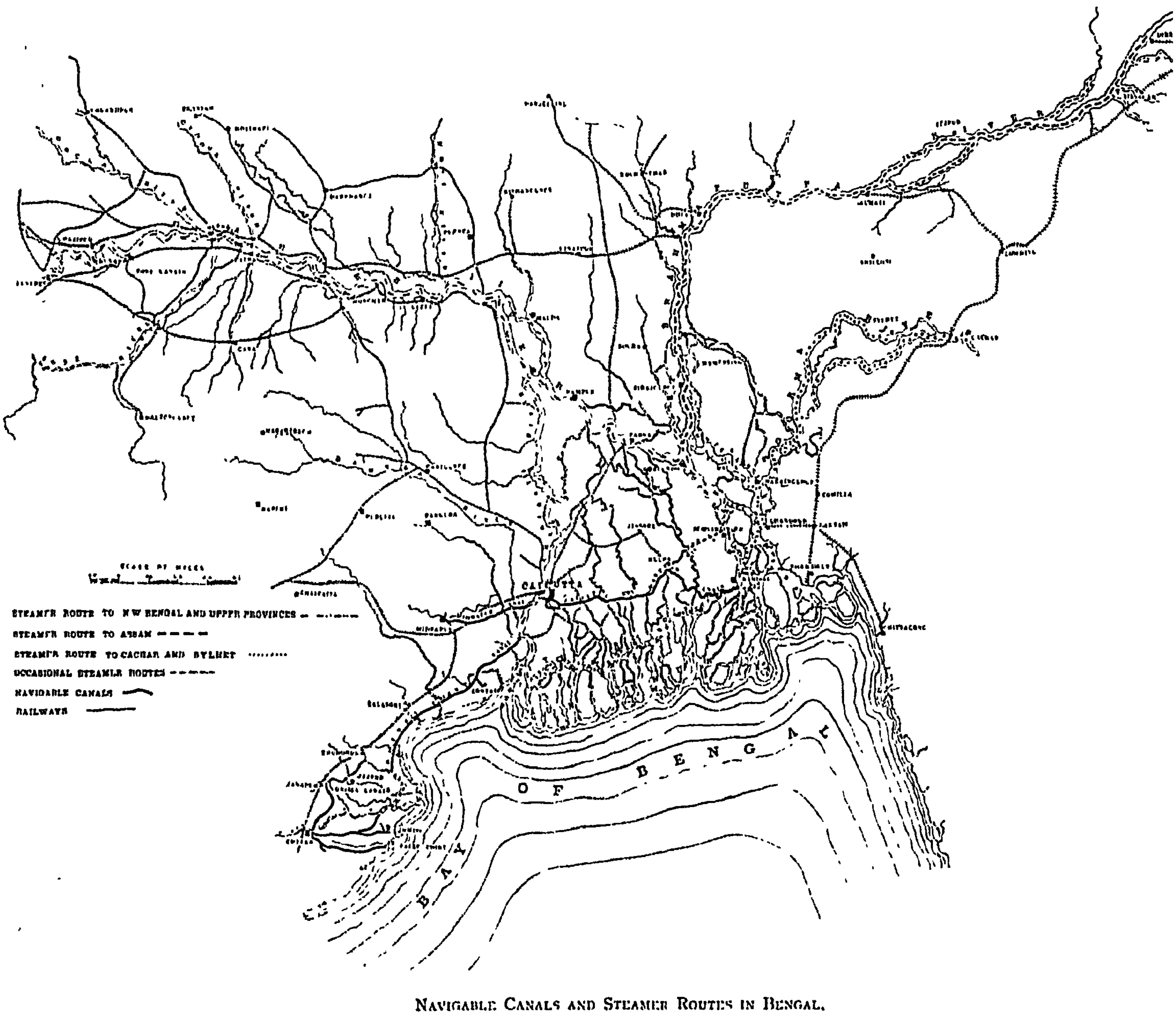
Navigating the Ganges in 1844.



Navigating the Ganges in 1904.

[*To face page* 254.

The importance of the water-borne trade of Northern India is clearly demonstrated by the last "Report of Trade Carried by Rail and River in Bengal," where it is said that "of the total trade of Calcutta with Bengal and other provinces, more than one-half, estimated by value, is carried by river, and the river-borne trade of Bengal with other provinces (including the trade with Calcutta) exceeds one-third of the whole inland trade."

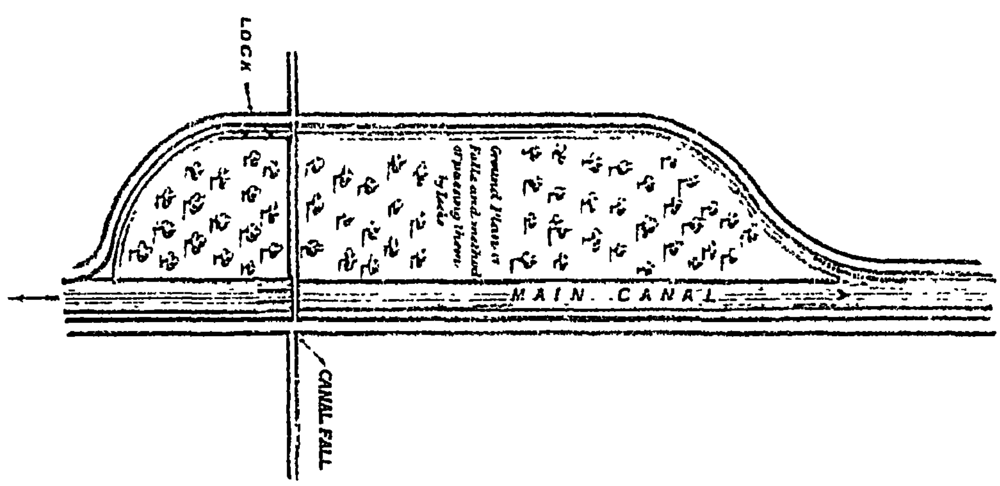


NAVIGABLE CANALS AND STEAMER ROUTES IN BENGAL.

The water-borne traffic of Northern Bengal, and that coming down the Ganges from Upper India, finds its way, during the rainy season, when the rivers are high, down the Ganges, the Bhagirati (or one of the other Nadia rivers) and the Hoogly, to Calcutta. When the Bhagirati becomes choked by sand banks in the dry season, the traffic has to pass down the Ganges, past Goalundo, to Barisal and then through the Sunderbuns to Calcutta. This route is 300 or 400 miles longer than that by the Bhagirati and more dangerous to the boats. The water-borne traffic from Midnapore and Orissa is carried by the Orissa, the Orissa Coast,

and the Midnapore Canals; but it has been greatly affected by the competition of the Bengal-Nagpur Railway, which has put on extremely low rates specially to tap the canal traffic.

The artificial canals of Bengal are, however, of little importance compared with the magnificent rivers, which bear a vast volume of goods, both in the old-world native craft and in the steamers and flats of the various steamer companies. Steamers proceed from Calcutta to Cachar and Sylhet by the Sunderbun channels, the Megna, and the Soorma; to Assam by the Brahmaputra; to North-West Bengal and Behar, in the rainy season, by the Hoogly, the Bhagirati and the Ganges; to the Upper Provinces by the Ganges and the Gogra. In all these routes the navigation is impeded, in the dry season, by sand banks. In many of the rivers in Bengal it would be possible, by dredging and by training works of various kinds, to improve the navigation. So far little has been done. The question of internal water traffic stands now, in India, much as it stood in Europe at the middle of the last century. The mind of the Government has been absorbed in the extensions of the railways, and little or nothing has been done for the waterways. In Europe the policy of free waterways has, rightly or wrongly, been largely adopted, whereas India now imposes tolls—heavy tolls in many cases



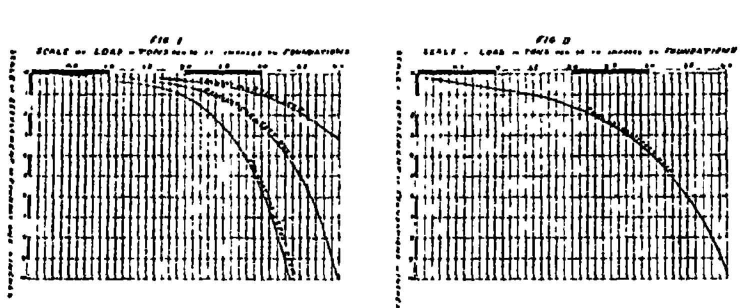
SITUATION OF LOCK AND FALL ON THE GANGES CANAL.

—not only on all artificial canals but even on the few natural waterways (such as the Nadia rivers and the Sunderbun channels) which are, to some extent, maintained by the State for purposes of navigation.

There are signs that there is a change of attitude in India on this subject. The opinion gains ground that, if the State may justifiably spend public funds on the maintenance of free roads; if it may construct and maintain, largely from public funds, such unremunerative railways as the Assam-Bengal line; it may also be right to follow the lead of other nations and spend public funds on the maintenance and improvement of the many natural waterways which intersect parts of the country. It is proposed to provide large dredgers to clear sand banks from the Bhagirati and other channels; it is proposed to open up the "Bhil route," near Madaripore, so as to make it navigable for large steamers all the year round and thus largely decrease the distance which all steamers have to travel through the Sunderbuns: it is proposed to canalise Tolleys Nullah, near Calcutta, and to improve several other routes. Such improvements will increase the facilities for steamer and boat traffic very greatly. The opinion that it is the duty of the State to spend public money on the construction and maintenance of waterways for the benefit of the community is, obviously, one which is open to dispute. But,

whether this view is correct or not, it is one which has found acceptance in many countries, and those countries which do adopt it offer to their merchants a very material advantage in their competition with the merchants of other countries which do not adopt it.

The sketch on page 221 shows one system of placing the lock and fall of a navigable canal at a point where a drop occurs in the canal bed. In that case the channel carrying the supply is diverted to the fall or weir, and the lock is placed on the centre line of the main canal; this is the system usually followed in Southern India and Bengal. On the Ganges Canal exactly the opposite procedure was adopted, as shown in the sketch on page 256, the lock being placed on the side channel and the main canal being carried straight through on its true alignment over the fall. This system is preferable in those cases where the discharge is very large, but a lock channel of so great a length is open to serious objection where there is much silt in the water, for in that case it rapidly fills up with deposit. On the Sirhind Canal the locks and falls (see Plate on page 222) are built together, as is commonly done in France: this system keeps the lock channel clear of silt, but it is objectionable, especially where there are large unwieldy boats to deal with, on account of the difficulty in getting the vessels into the lock; the stream to the weir produces a current across the mouth of the lock, and boats cannot easily be kept in their proper course, but are liable either to be drawn into the weir channel or to run with some shock against the lock walls.

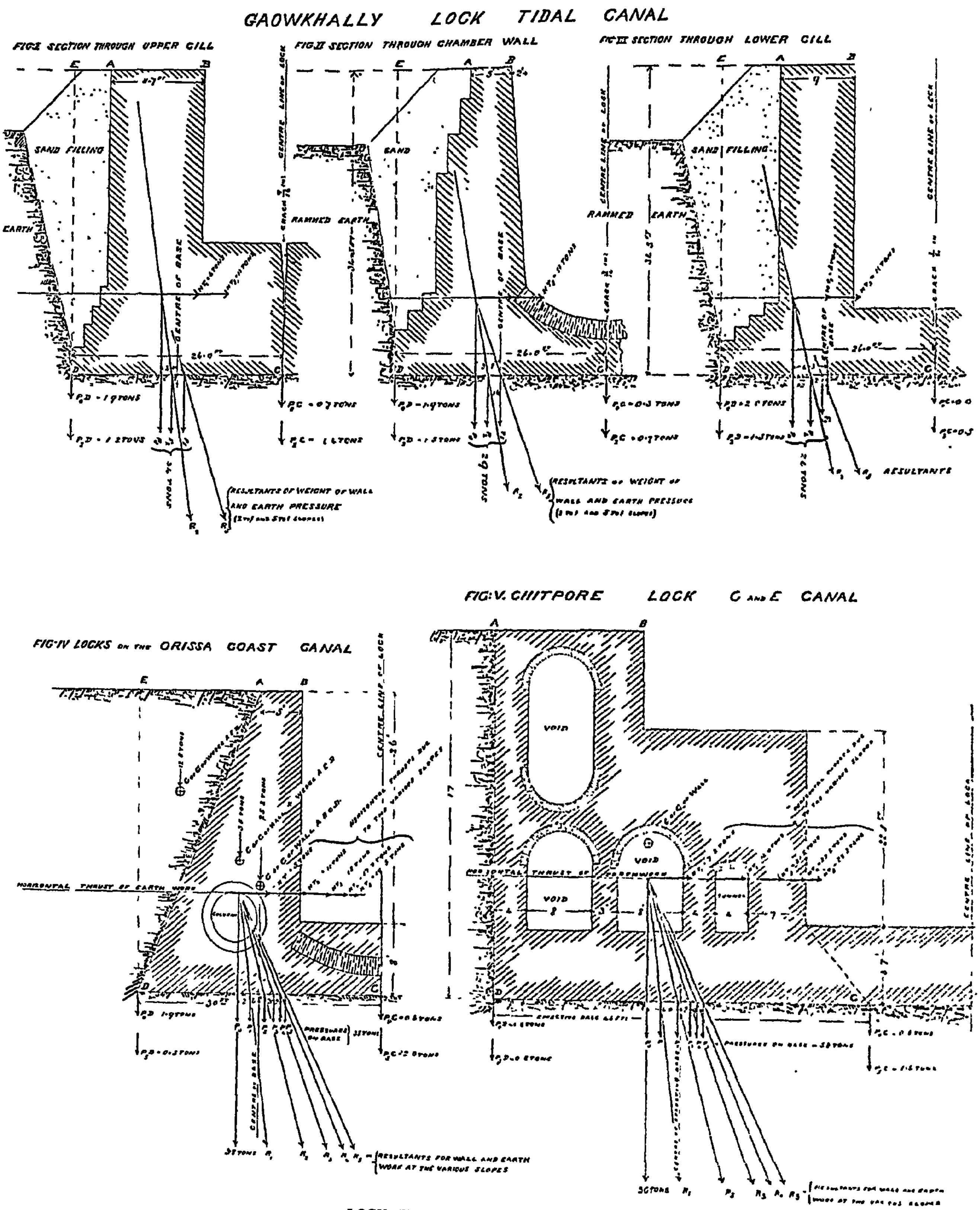


DIAGRAMS OF SETTLEMENT OF FOUNDATIONS

The Plates on pages 258 and 260 give the plans of locks which have been constructed on the alluvial soil of Lower Bengal. It is not an uncommon occurrence that locks crack longitudinally down the centre of the chamber. In Lower Bengal this defect has frequently occurred; indeed, all the locks on the Hidgellee Tidal Canal cracked in this way. The soil in the delta of the Ganges river is of a very treacherous nature; the upper crust for a depth perhaps of 8 to 12 feet is sometimes light-coloured and loamy, but the lower soil is a bluish-black clay, which, when thoroughly dry, cakes hard, and cracks a good deal by contraction, but when wet is slimy and liable to sudden slips. This soil will sometimes stand in canal banks for years at a $1\frac{1}{2}$ to 1 slope, and will then subside in places to a much smaller slope, upheaving the bed of the canal below it. A movement of this nature occurred in the Calcutta Docks in 1890, and is described in a report[1] which tends to show that the angle of repose of this soil may be as small as $7\frac{1}{2}$ to 1, although it will stand under certain circumstances at $1\frac{1}{2}$ to 1, and even at a steeper slope. In the black soil, trunks of trees and layers of peaty matter are found, which probably account in some degree for the treacherous nature of the subsoil. Experiments were made by Mr. Leonard, in 1873, to determine the amount of settlement which would be produced by imposing various loads on this soil at different depths from the surface; and Mr. Apjohn (in a note written in 1881, from which the following facts are largely taken) deduced the above diagrams from these experiments. Fig. I. shows the results in the upper loamy soil, and Fig. II. those in the bluish-black clay.

The experiments on which these diagrams are based were made near Calcutta, on piers built at the different depths stated, which had a bearing surface of 10·24 square feet each.

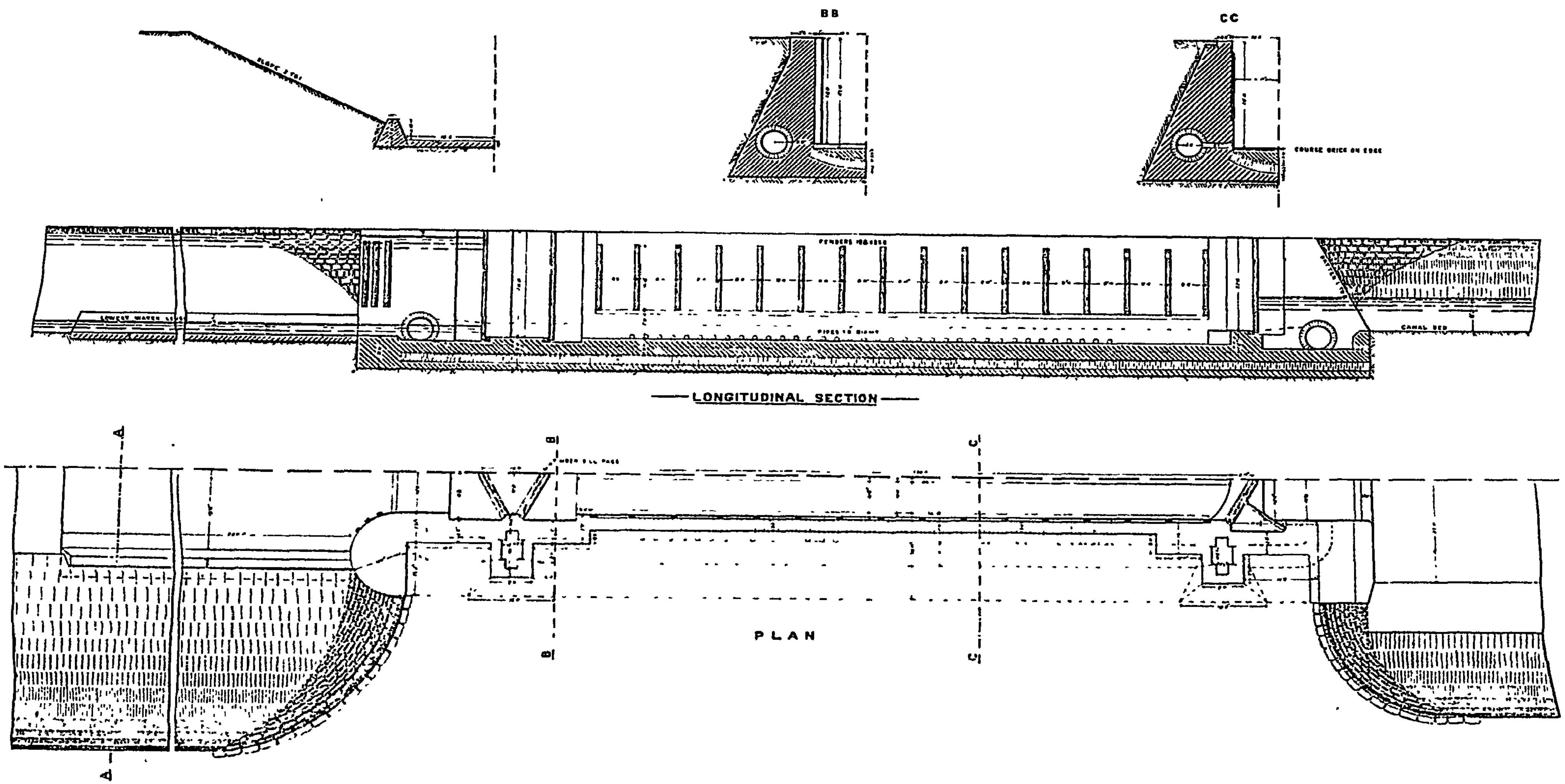
[1] Report by Mr. J. H. Apjohn, Engineer to the Calcutta Port Commissioners, on the recent movements of the walls of dock No. 1, dated December 1st, 1890.



LOCK WALLS ON BENGAL CANALS.

They were loaded so as to induce a pressure varying from 1·5 to 8·7 tons per square foot. Each pillar was loaded with three different weights, increasing by a ton per square foot, and the weights were left on until no further sinkage could be observed. The experiments were perhaps not sufficiently numerous to justify the formation of any general law upon the recorded facts, but, working on these experiments, Mr. Apjohn drew the conclusions that the curves representing the settlements were hyperbolas, the amount of settlement increasing in a geometrical ratio as the pressure itself increased arithmetically; that the ratio of each geometrical series pertaining to the respective depths decreased with the depth, and that the rate of decrease appeared to conform to a law, viz., that as the depth of foundations subjected to pressure increases in arithmetical progression, the ratio of the geometrical series, representing the rate of sinkage, decreases in a geometrical series of which the ratio is less than unity. However this may be, it is evident that great care is necessary in founding any masonry structure on such soil as that referred to in Fig. II., in which a pressure of one ton on the square foot causes a settlement of 1 inch, and a pressure of four tons causes a settlement of 10 inches. For, unless the pressure on the foundations is fairly equal all over the area of them, there must be unequal settlement, and consequently cracks in the masonry. The results of unequal pressures are clearly shown by an investigation which Mr. Apjohn made of the strains imposed on a lock wall founded on this soil. The particular case taken was that of the Gaowkhally Lock, in Bengal, which cracked in the manner shown in the Plate on page 258, although special care was taken in its construction. A wedge of sand, weighing 90 lbs. to the cubic foot, was introduced behind the walls, and the earth backing, which was not carried up to the full height of the wall, was thoroughly consolidated by ramming. The earth itself weighed about 112 lbs. to the cubic foot, so the sand had the effect of reducing the vertical pressure on the back footings of the foundation; but the thorough consolidation of the earth backing had the effect of reducing the pressure exerted by it against the back of the wall, which appears to have been a disadvantage, for as the crack in the floor was due to the wall falling backward, it is evident that the crack might have been avoided had the pressure against the back of the wall been greater. Indeed, it is probable that at the time the lock cracked, which was before any water was admitted to it, the earth pressure was practically confined to that due to the sand filling alone, and that the earth backing exerted no thrust. The sections (Figs. I., II., and III.) show the three principal parts of the lock wall. P in each case is the vertical component of the thrust of the earthwork, and of the weight of a section of the wall 1 foot in length, that is to say, P is the weight of the wall and the wedge of backing A E D which lies vertically over the foundations. P_0 shows the point of application of P, when there is no earth thrust, P_1 when the thrust is due to an angle of repose of 1 to 1, P_2 when the angle of repose is 2 to 1, and so on. H T_2 is the horizontal thrust of the earthwork when the angle of repose is taken as 2 to 1, H T_5 when the same angle is taken as 5 to 1.

The line drawn vertically through P_0 passes through the centre of gravity of the wall and wedge A E D combined, and it cuts the base C D at a point which is the centre of pressure on the base *if the horizontal thrust is not in operation.* If the horizontal thrust is taken to be in operation, and is that due to an angle of repose of 2 to 1, the vertical component of the total pressures acting on the base is P_2, acting at the point where the resultant R_2 of the earth pressure and weight of the wall cuts the base C D. P_2 is, of course, equal in amount to P_0, but is transferred nearer to the centre of the lock by the action of the horizontal thrust of the earthwork. The pressure P_0 D and P_0 C represent the intensity of pressure at the points D and C respectively, caused by the force P_0 acting at its point of application: P_2 C and P_2 D being the corresponding pressures due to P_2. Thus, taking

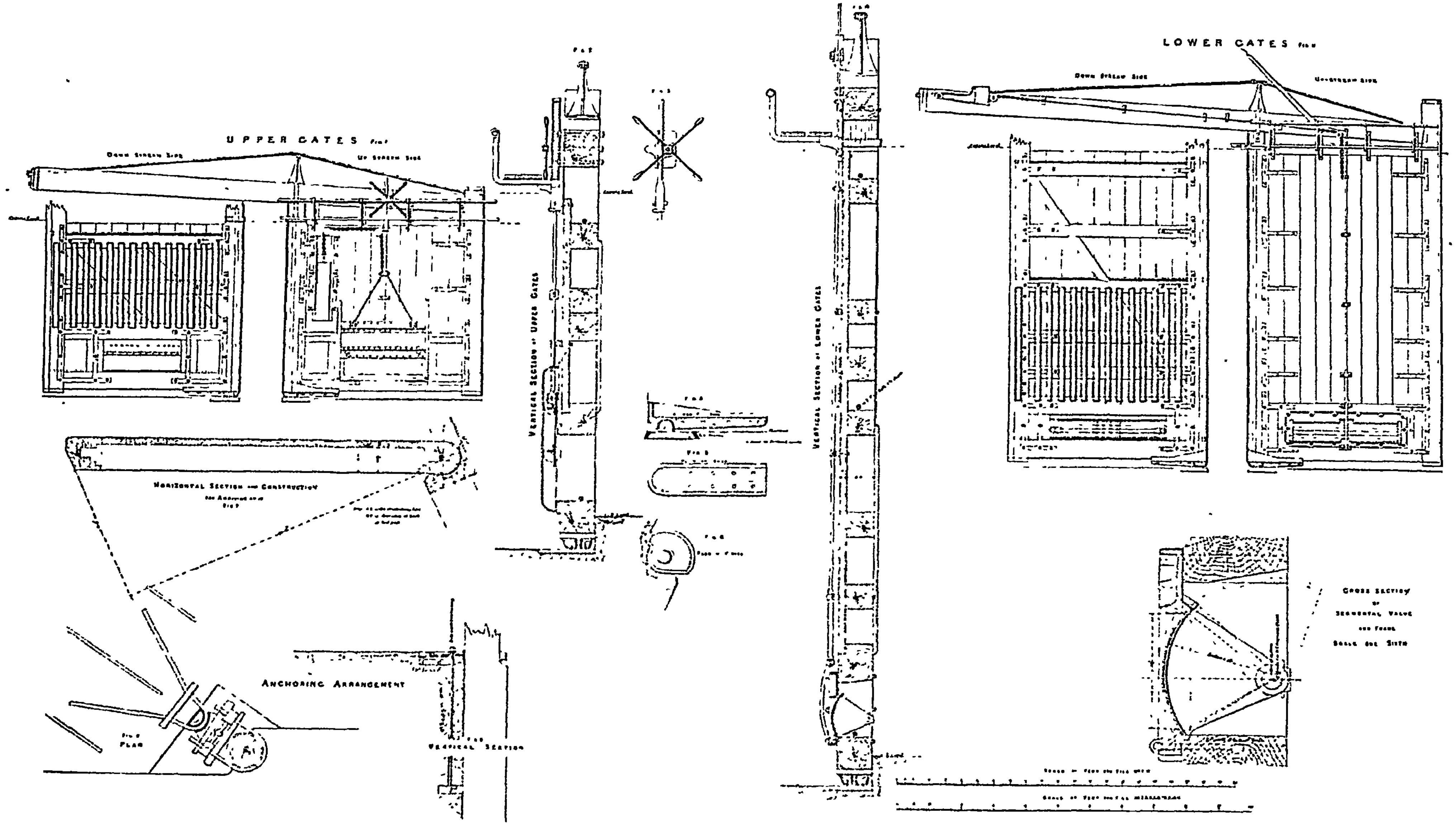


TIDAL LOCK ON THE ORISSA COAST CANAL

the case of the section through the chamber wall, the total pressure on the base of the wall is 29 tons, or an average of 1·2 tons nearly per square foot, on the 26-foot base: if the earth backing exerts no horizontal thrust, then the centre of pressure is on the line P_0 and the pressure (P_0 D) at D is 1·9 tons per square foot and the pressure (P_0 C) at C is 0·3 ton per square foot. It will be seen from the second diagram on page 257 that a pressure of 1·9 tons would cause a settlement of about 1½ inches, but a pressure of 0·3 ton would cause a settlement of about one-third of an inch only. If the horizontal thrust of the earthwork (calculated on a 2 to 1 slope) is brought into account, the pressure at D (P_2 D) becomes 1·5 tons per square foot, and that at C becomes 0·7 ton; the settlements due to these pressures are about 1 inch and ½ inch respectively, which would be sufficient to crack the floor, though hardly to the extent shown; and it is very probable, as has been already stated, that at the time the floor did crack, the earth did not exert any horizontal pressure. Had the earthwork not been so carefully rammed, but left to exert the full pressure due to its natural angle of repose, the extent of the cracks would have been less; they would have been entirely prevented if the earth thrust had been sufficient to cause the resultant to pass through the centre of figure of the base of the wall. It will be seen that this would have been the case in Fig. II. if the angle of repose had been 5 to 1 and the earth backing had exerted the full pressure due to that slope: but that even with that angle of repose the resultant of Fig. III. still passes at the back of the centre of the base.

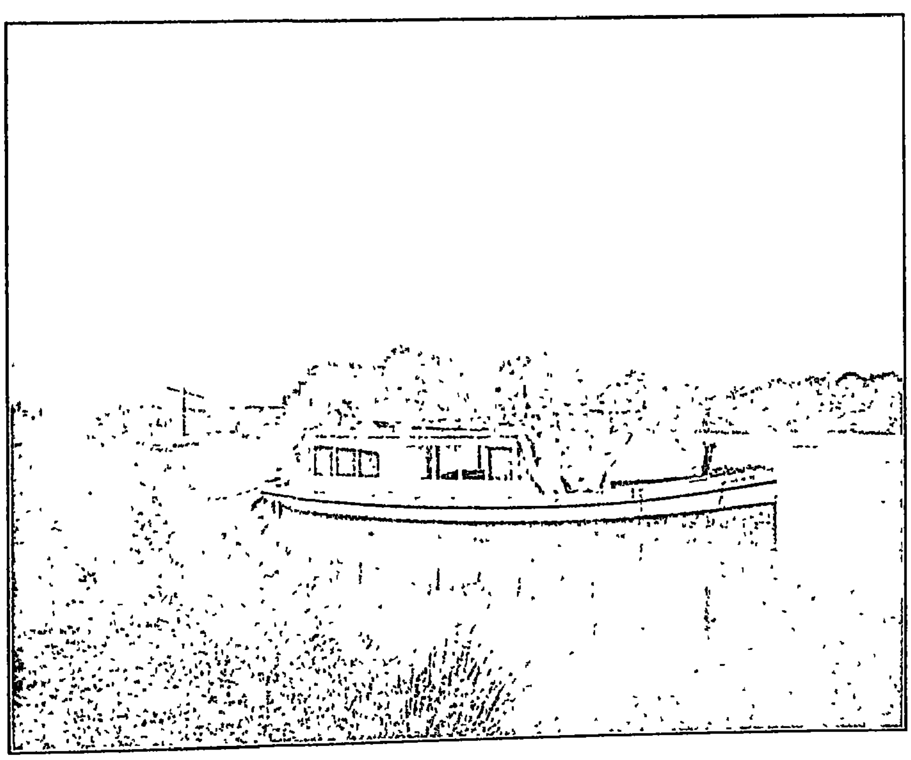
The cause, then, of the cracks which have often occurred in lock floors is, primarily, that the design of the walls has been such that the centre of pressure of the weight of the wall and superincumbent earth (E B D) fell so far behind the centre of figure of the base that the unequal pressures, brought upon the surface of the base, caused unequal settlements sufficient to crack the floor. And a secondary cause was the insufficient support afforded to the wall by the earth pressure. It is noticeable that in most cases these cracks have appeared before water was admitted to the lock, and often before the walls were raised to their full height: the water pressure would, of course, tend to increase the backward motion of the wall and to increase the evil. The section of the main walls of the older locks varied a good deal in different parts—the tail-bay, fore-bay, counter-forts, and chamber—so that any tendency to crack was increased by the unequal pressures resulting from these changes, and long wing walls were built which were liable to unequal settlement.

In the more recent locks (Plates on pages 258 and 260), which have been built in the soft soil of Lower Bengal, wing walls have been omitted and the earth slopes have been retained by laterite revetments (which can settle without affecting the lock), and the section of the lock walls has been kept more uniform. Fig. IV., page 258, is a section of the lock wall adopted on the Coast Canal: the centre of gravity of the wall alone lies immediately above the centre of figure of the base, and the centre of gravity of the wall together with the superincumbent earth (A E D) lies 2·6 feet behind the centre of the base; so that, if the earth backing exerted no horizontal thrust at all, the pressure at D (P_0 D) would be 1·9 tons and at C (P_0 C) 0·6 ton. But the backing was tipped in behind the wall and not rammed, so that it must certainly have exerted some pressure on the wall. The horizontal thrusts due to the angles of repose of 1 to 1, 2 to 1, &c., are shown as H T_1, H T_2, &c., and the lines of action of the resultants are shown as R_1, R_2, R_3, &c. It will be noticed that when the angle of repose is 2 to 1, the resultant R_2 passes almost through the centre of the base; so that, if that angle was the true one, the pressure on the base would be uniform throughout. It is probable that the true angle is less than 2 to 1, and that the resultants have been thrown further in toward the centre of the locks: for these locks have not cracked. If the line of action of the resultants cuts the base on the



LOCK GATES ON THE MIDNAPORE CANAL

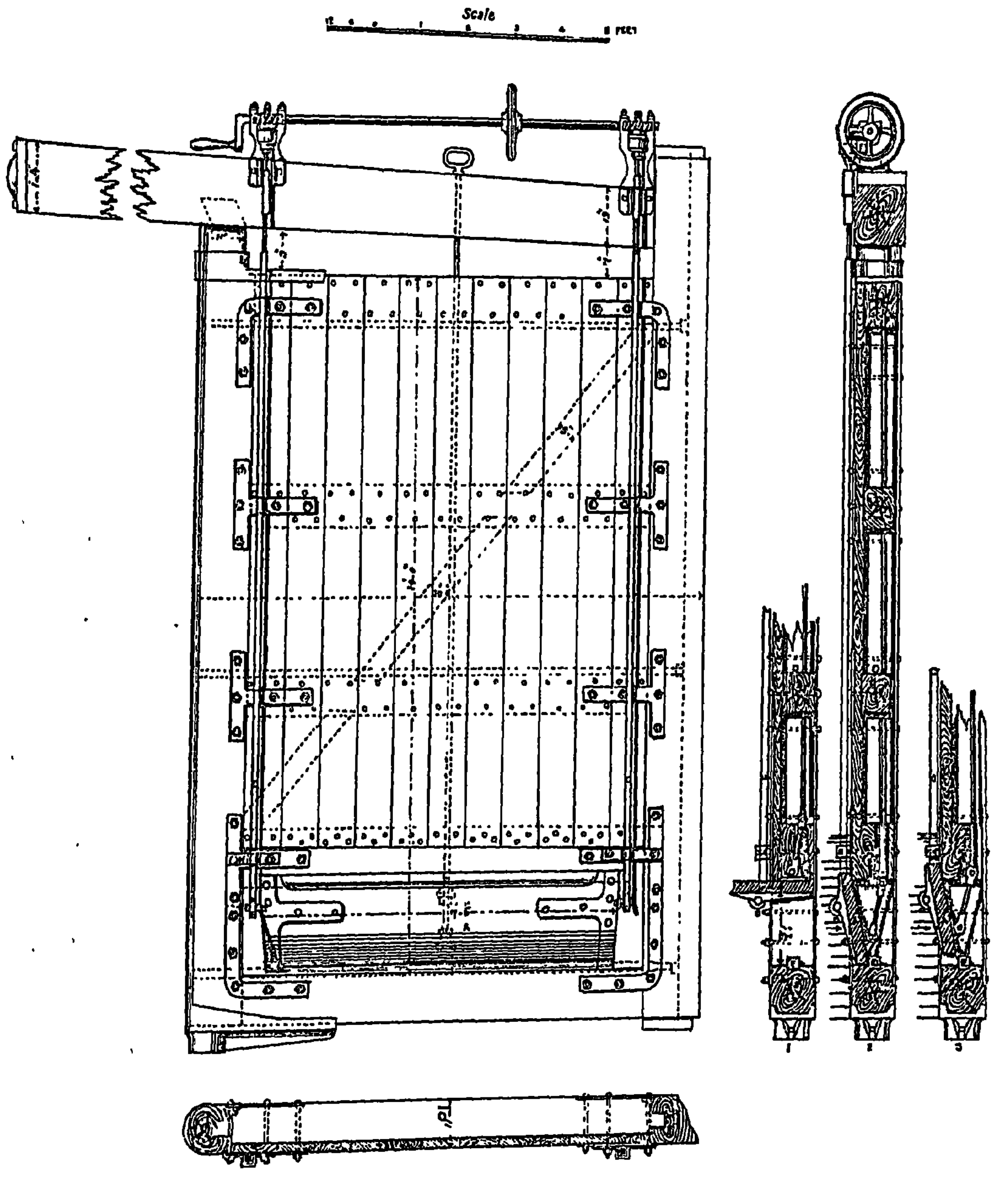
A Navigable Canal, Sone Canals



Officers' Inspection Boat, Midnapore Canal.

[To face page 262

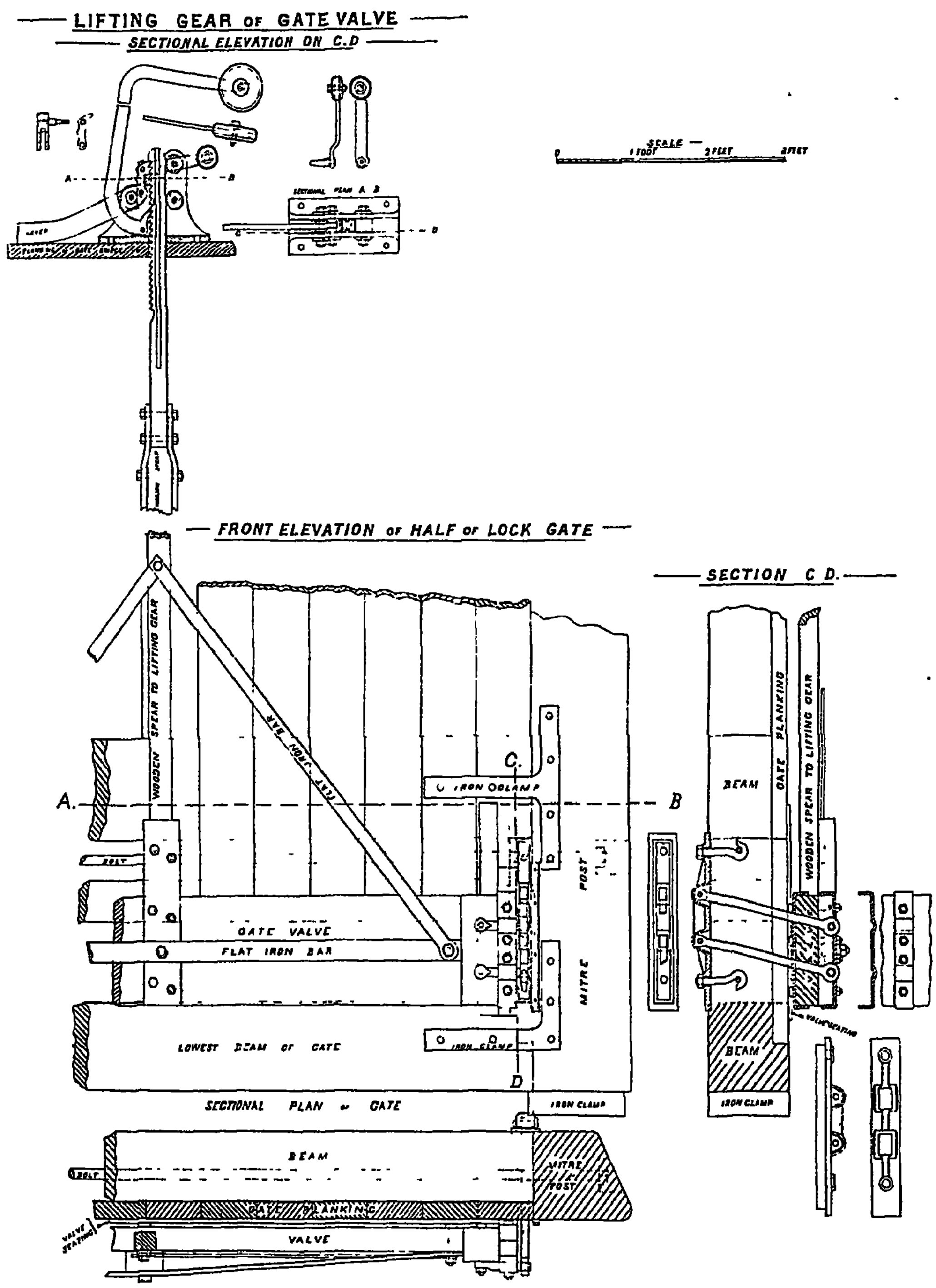
inner side of the centre of the base, the tendency of course is for the wall to fall forward: it is better that the tendency should be in this direction, because the floor counteracts any forward motion of the wall, and the water pressure does the same. It will be noticed that even with an angle of repose of 5 to 1 the resultant cuts the base only 3·2 feet from the centre of it. In constructing works on this soft soil it is most desirable to avoid unequal pressures during the



"Ek-Dum" Valve on Orissa Lock Gates.

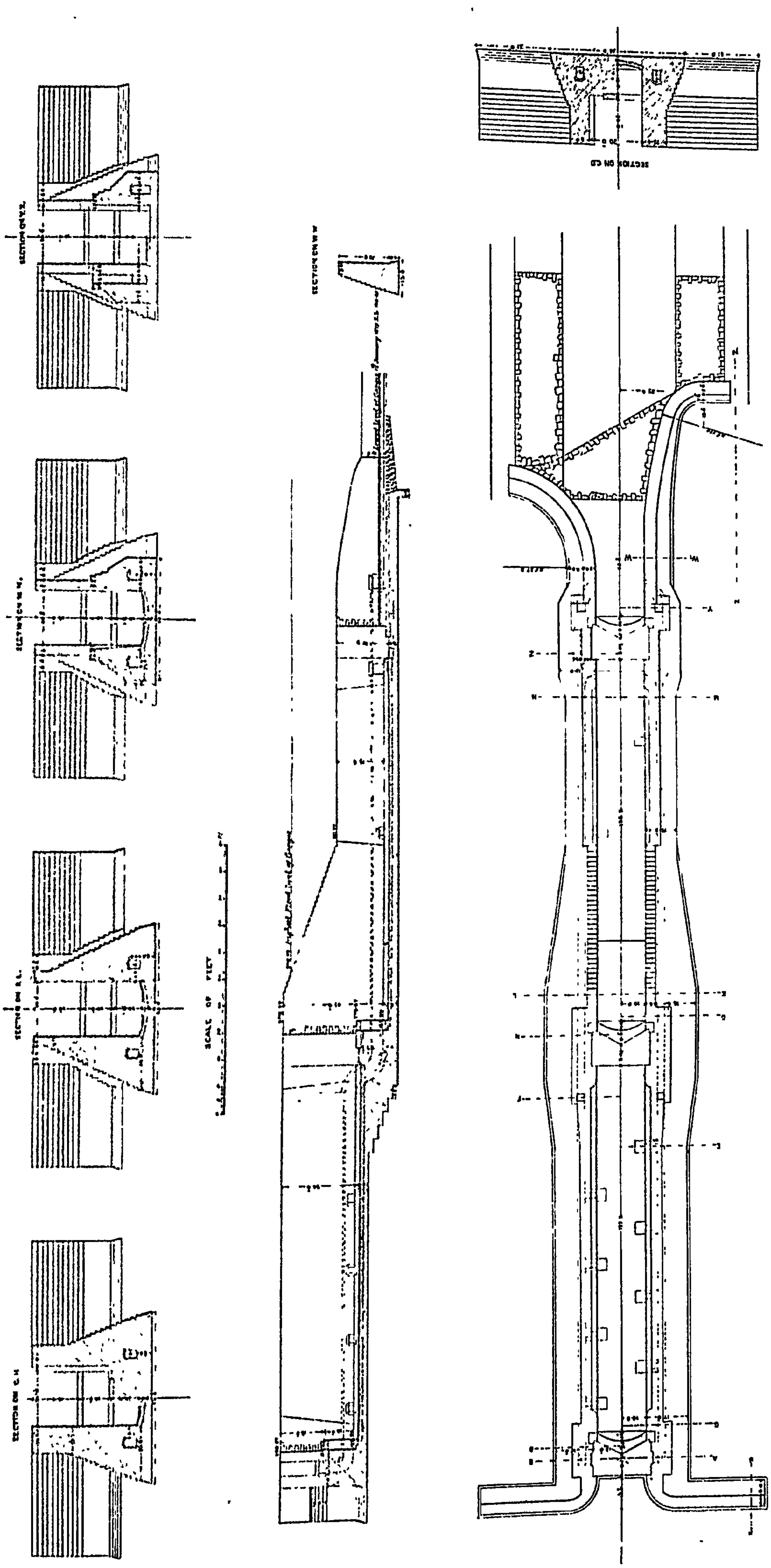
progress of the work, so that the settlement of the foundations, which must occur, may proceed regularly. One of these Coast Canal locks sank 12 inches bodily during its construction. If different horizontal sections of the wall in Fig. IV. are taken and the earth backing is kept up to the level of the top of the section, it will be found that, with an angle of repose of 2 to 1, the pressures on the base are nearly equalised, so that as the building progressed the lock sank equally all over its foundation.

Unequal pressures are, of course, greatly reduced by increased width of base. In the Gaowkhally lock the base was 0·75 of the height: in the Orissa Coast Canal locks the base

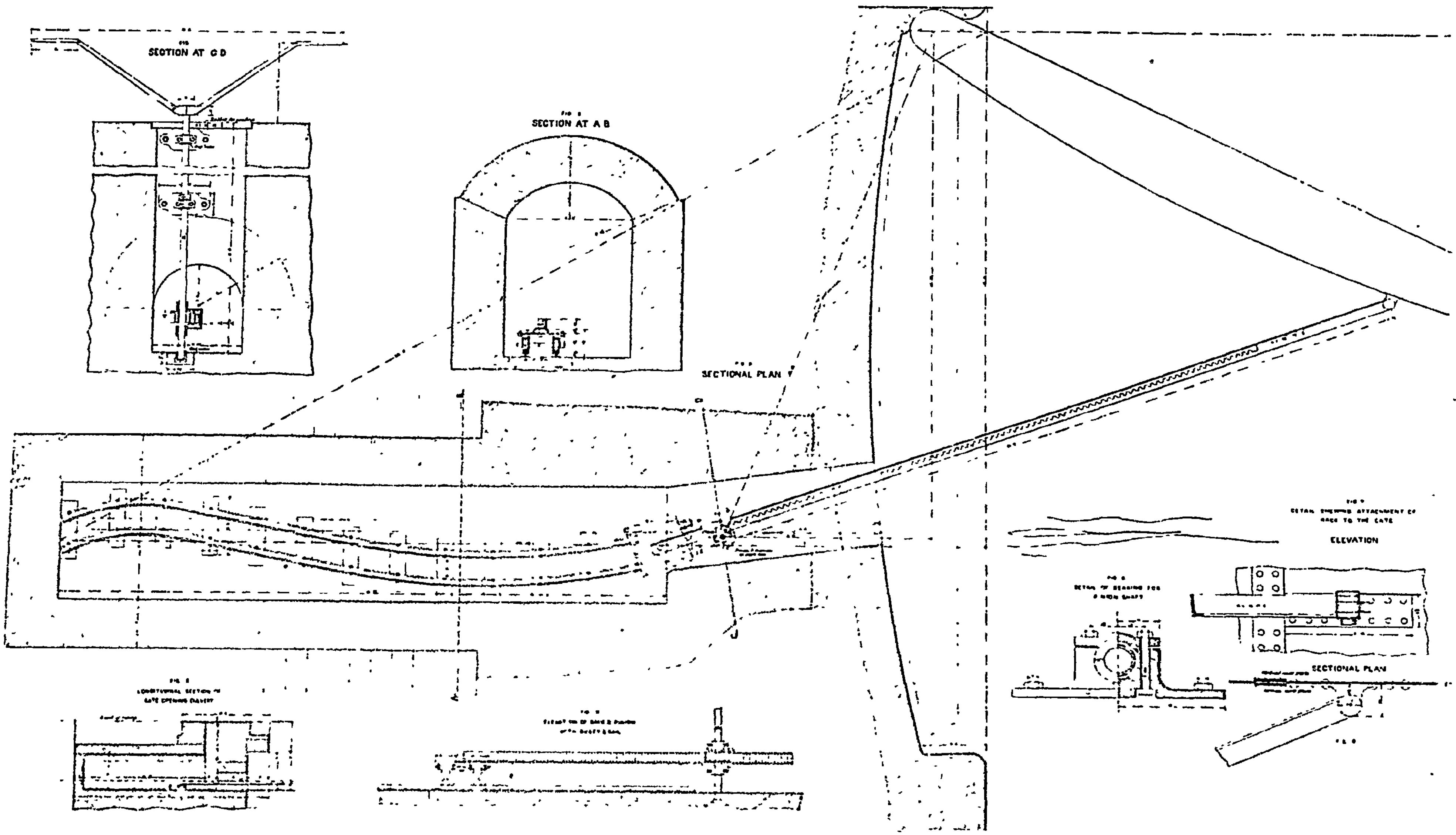


Lock Gate Valve on the Sone Canals.

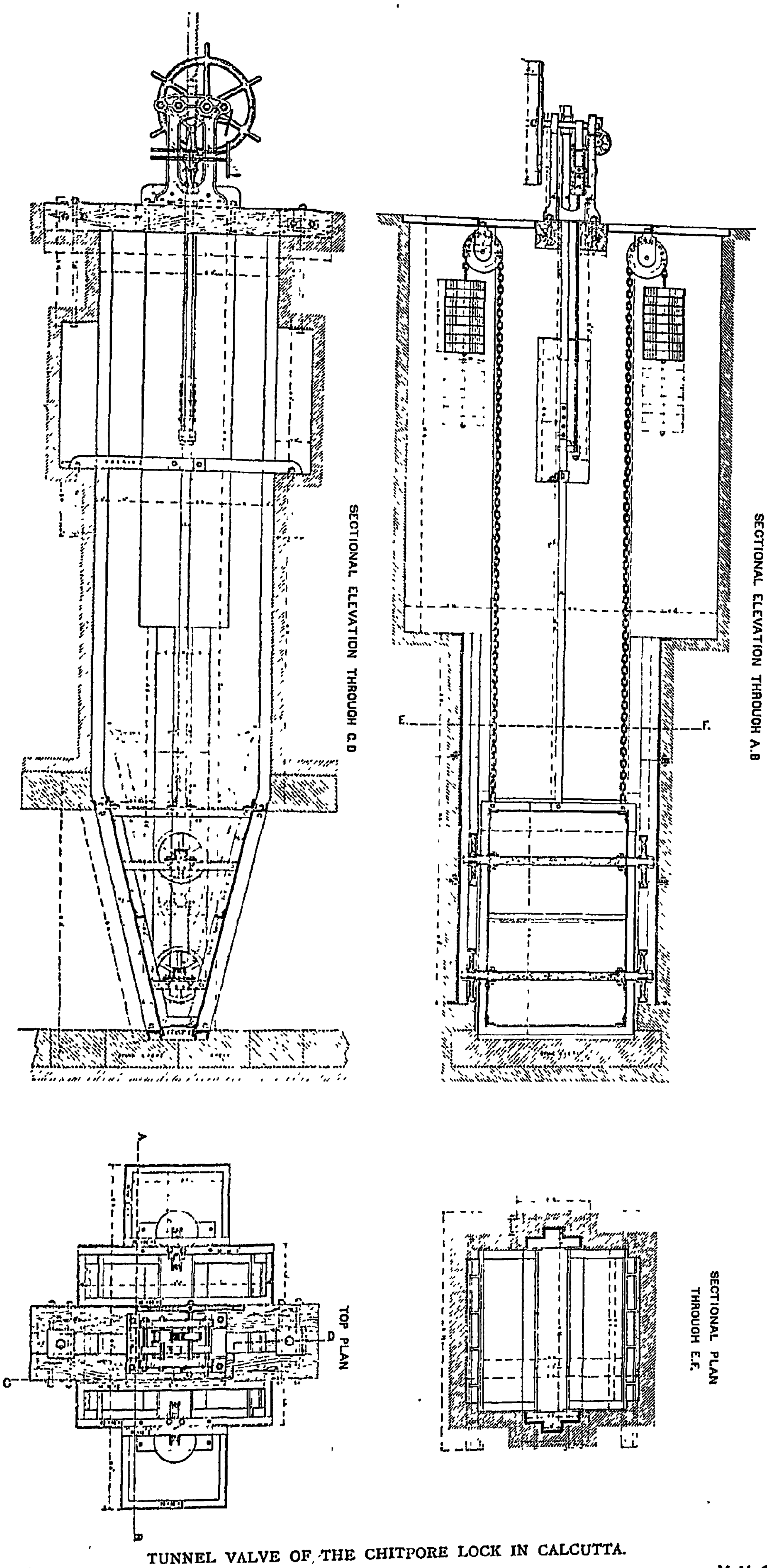
was nearly 0·90 of the height, and in the Chitpore lock the base was 1·1 of the height. In the latter case (see Plate opposite page 258, and Fig. V. on page 258) the back of the wall was



DOUBLE LOCK ON THE SONE CANALS IN BENGAL.



LOCK GATE OPENING GEAR IN BENGAL.



TUNNEL VALVE OF THE CHITPORE LOCK IN CALCUTTA.

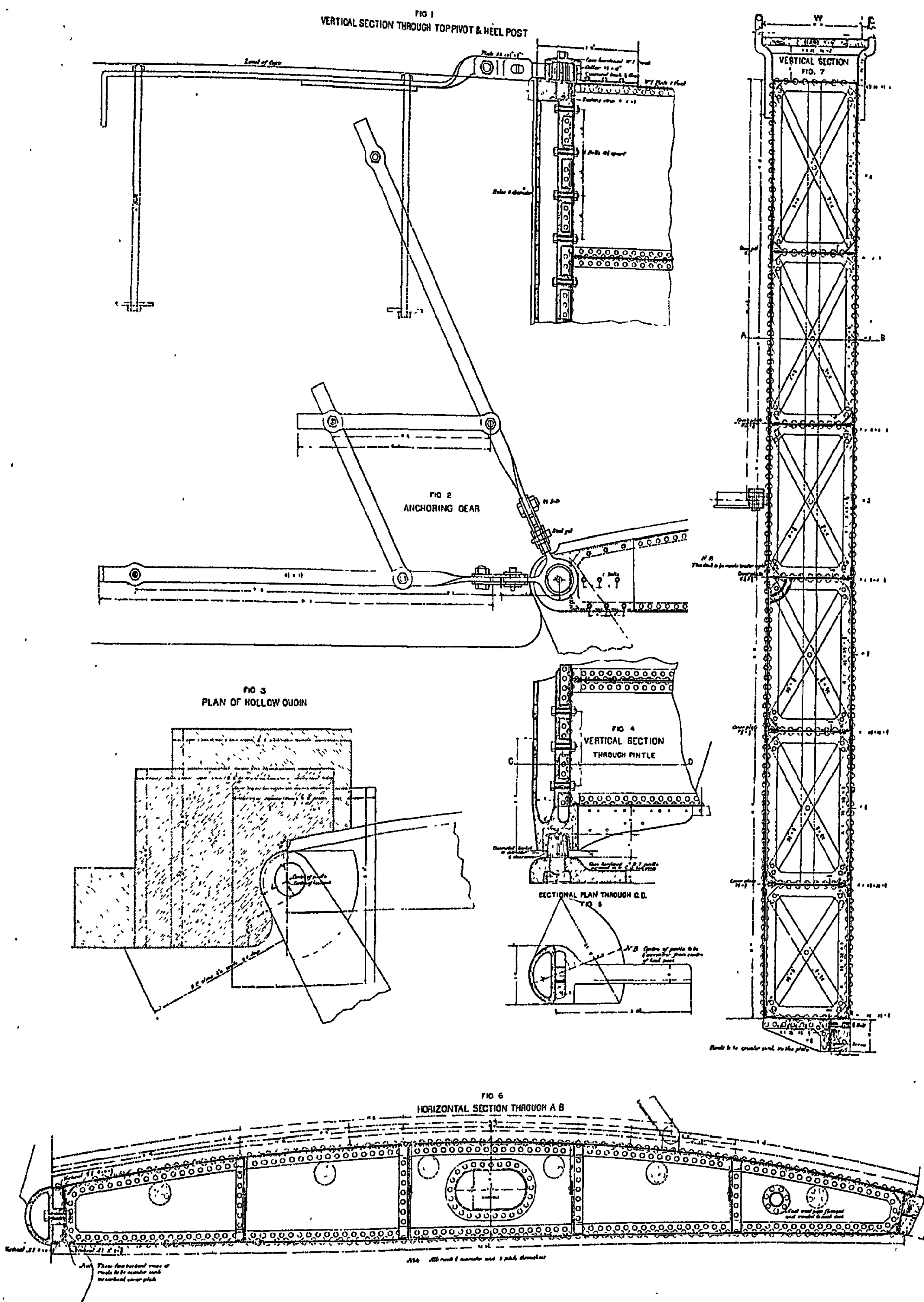
lightened by voids, so that, with earth pressure calculated at an angle of repose of 2 to 1, the resultant of that pressure and the weight of the wall passed through the centre of figure of the effective base.

In all works built on soil liable to settlement in the manner indicated by the diagrams on page 257, and of which the angle of repose is so uncertain, the resultants of the earth pressure and weight of wall (taking any probable angles of repose—say, from 1·to 1 to 5 to 1) should fall within a distance of the centre of figure of the base not greater than about one-tenth part of the width of the base.

The Plate on page 265 shows a double lock, and the Plates on pages 262 and 263 show the timber lock gates, with balance beams, which have been erected on the Orissa and Midnapore Canals in Bengal, with the various forms of gate-valves which have been employed. The semi-cylindrical valve on the Midnapore canal gives great satisfaction, and so does the parallel bar valve, which was introduced by Mr. Fouracres on the Sone Canals. This valve is removed from its seating by the action of the parallel bars, as soon as the spear by which it is connected to the lifting gear has been raised slightly, so that there is no friction to be overcome. It is lifted by a rack and lever by one man in about thirty seconds, and is closed by simply turning the paul out of the rack, when it falls by its own weight. The various arrangements shown in these Plates are all more expensive than an ordinary draw-valve lifted by rack and gearing, and it is questionable whether they offer corresponding advantages.

Lock gates in the older works were actuated by balance beams, but these are now rarely used. In Bengal all new lock gates are actuated by the arrangement shown in the Plate on page 266, which was also introduced by Mr. Fouracres. The example in the illustration was designed for the Chitpore lock, which is 40 feet in the clear, but in smaller locks the rack is hinged to the top of the gate and the gearing for actuating it rests on the lock wall. In that case the pinion working in the rack is mounted in a small triangular box, which is pivoted in the masonry, so that it can adjust itself to the angle assumed by the rack. The pinion is keyed to a shaft which is turned by a handle similar to that in the Plate.

The Plate on page 267 shows the valve which has been successfully erected on the Chitpore lock. The important point in connection with it is the ease and speed with which it can be opened: it has the objection that it cannot be readily closed, in case of any accident, until the difference in level between the water within and without the lock is small. This kind of valve has been fitted to the locks on the Orissa Coast Canal. The valve or culvert filling gear which is used on the Midnapore Canal and in Orissa is fitted with a water balance bucket in a well over the filling culvert. The arrangement is cumbersome and expensive, but it is easily manipulated. The iron gates of the Chitpore lock, which are illustrated in the Plate on page 269, were designed with a water-tight compartment below the water line, with the object of partially floating the gate, so as to relieve the strain on the anchor irons. These gates are rather too light in structure, and great difficulty was experienced in making the compartments water-tight.



IRON GATES OF THE CHITPORE LOCK.

CHAPTER XV.

DUTY OF WATER.

Definition of the "Duty" of Water—Duties expressed in different Forms—Base of Duties—Duties in *Khareef* and *Rabi* Seasons—Duty "at the Head" and Duty "Utilised"—Duties in Canals and Distributaries—Variations in Duties due to Soil, &c.—Great Variation in Duties—Low Duties display Waste—Duties during Periods of Pressure—Duties for Rice Irrigation in Bengal and Madras—Duties for Rabi Irrigation—Experiments on Duties—Duty of Water in Egypt—Gauging Canals to ascertain Duties—Duties largely affected by Care in Distribution—Irrigation by Rotation or "Tatils"—Trouble and Perseverance required to establish "Tatils"—An Example of "Tatil" Tables.

THE "duty" of water, in the language of the Indian irrigation official, may be defined as the area of crop which can be matured by a given quantity of water. Duties vary very greatly, and must necessarily do so. At first sight the great variations which are found in the records of duties, and the difficulties which are known to exist in recording all the essential facts accurately, leads to the opinion that duties are unreliable and misleading; it must be admitted that great care is necessary in dealing with them, and that serious errors have arisen from their misuse. But, since no irrigation project can be intelligently designed without calculation of the quantity of water needed for the irrigation of the crops, a study of duties is of great importance; and, if the fact is borne in mind that what it is most desirable to know is the duty of water under unfavourable circumstances when crops most need irrigation, and not the duty under favourable conditions, when, possibly, no water at all may be essential, it is more easy to seek for sound data for the necessary calculations.

The duty of water varies primarily with the crop. Rice needs more water than indigo, indigo more than wheat. It varies even more largely with the soil: sandy land—especially if the crop is rice—will take two and three times the water that clay soil will need. It varies, too, with the season: if the rainfall is scanty, the more need for water. It varies also with the condition of the channels: flat shallow channels will often give smaller duties than steeper and deeper ones. It varies with the distance the water has to be carried in the channels, owing to the loss on the road. And it varies in no small degree with the skill with which the distribution of the water is managed, not only by the cultivators, but by the canal officers.

In India it is usual to take 1 cubic foot per second as the unit of quantity, and the whole period during which a crop requires water to bring it to maturity as the time during which the flow of 1 cubic foot per second continues. Thus, when it is said that the duty of water in the *khareef* (monsoon) season of a certain canal is eighty acres *at the head*, the statement implies that the total volume of water which passed into the head of the canal during the entire *khareef* season had been ascertained, and the average discharge per second had been calculated, and that eighty acres of crop had been matured by each cubic foot of water per second which had, on the average, passed into the head of the canal. The duty, especially in the case of works where the water is stored in tanks or reservoirs, is sometimes expressed in terms of the volume of water used per acre; thus, if the duty of the water of a tank is said to have been 200,000 cubic feet per acre, it means that on the average each volume of 200,000 cubic feet *drawn from the tank* was sufficient to mature one acre. Each way of expressing

the duty is easily convertible into the other, provided that the exact period of flow in the first case is known. The duty of water in different provinces in India is in most cases, unfortunately, simply expressed as so many acres to the cubic foot, and the period of flow, or *base* as it is now called, of the duty, is rarely stated; the base is occasionally given in the official returns and then the total volume of water used in irrigation can be ascertained. The following simple formulæ are useful:—

D = Duty of water, *i.e.*, the number of acres of crop matured by 1 cubic foot per second flowing continuously for a defined time.

B = Base of the duty, *i.e.*, the number of days during which the supply of 1 cubic foot per second runs in order to mature the crop defined by the duty.

Then—

$V = \frac{B}{D} \times 86{,}400$ = The volume of water in cubic feet used in maturing one acre of crop ... (I.)

$S = \frac{B}{D} \times 23{\cdot}8$ = Total aggregate depth, in inches, which the volume used would reach if distributed equally over the area irrigated ... ... (II.)

Further:—

If x = the discharge in cubic feet per second necessary to irrigate a given area of crops (A) with a given duty (D) and base (B):

Then—

$$x = \frac{A}{D} = \frac{A\,S}{B \times 23{\cdot}8} \quad \text{(III.)}$$

In America the duty of water is often expressed in "acre-feet." One "acre-foot" is the volume of water which is sufficient to cover an acre to a depth of 1 foot (43,560 cubic feet). This is taken as the unit of volume, and a reservoir is said to contain so many "acre-feet" and not so many millions of cubic feet or cubic yards. The duty of a particular reservoir is said to be so many "acre-feet" to the acre. In the United Provinces and in the Punjab the statistical tables now give a figure which is indicated by the Greek letter Δ; this is simply the aggregate depth of water on the field irrigated which would have been attained had all the water passing down the canal reached the field.

The duty of water may be gauged at all parts of an irrigation system, but it is usually stated, with reference to an entire system, on the discharge gauged in the canal below the head-sluice, and it is stated in two ways: first, on the basis of the discharge actually gauged as entering the canal, which is termed the discharge *at the head* of the system; and, secondly, on what is termed the discharge "utilised." The first way of stating the duty is useful, since it shows the quantity of water which it is necessary to draw from the source of supply—river, tank, or reservoir—in order to effect a certain result; but, inasmuch as the quantity of water on which the duty is based includes water wasted, run out at escapes, used in navigation, or lost in various ways, it is not a true gauge of the water used in the fields in which the crop is grown. The discharge "utilised" is obtained by deducting from the discharge "at the head" the quantities of water which are gauged as run out at escapes or used for other purposes: so the duty, based on the discharge "utilised," does become a true gauge of the quantity of water which it is necessary to draw simply for the purpose of irrigating and maturing a stated area of crop. It is not, however, an accurate measure of the quantity of water actually placed on the fields, because the deductions made from the discharge "*at the head*" include only known and measured losses, and they do not include the losses from percolation, absorption, and evaporation, which cannot be

accurately gauged. These losses are sometimes very great, especially where small areas are irrigated at a distance from the head of the canal, and they materially affect the duty which can be obtained from that portion of the supply taken in at the head which is "utilised." This explanation will enable the reader to grasp the true meaning of the statistics of duties which follow.

The two chief crops in northern and western India are the *khareef* and the *rabi* crops. The *khareef* crop is grown in the monsoon months (June to October), when there is the annual heavy rain. The *rabi* crop is grown during the cold season (generally November to March). The following table shows the duty of water entering the canal systems in the *khareef* season for three years on some of the older canals in different provinces:—

DUTY IN KHAREEF SEASON.

Province and Canal.	Number of Acres of Crop Matured by 1 Cubic Foot per Second.					
	At the Head of the Canal.			"Utilised."		
	1899—1900.	1900—01.	1901—02.	1899—1900.	1900—01.	1901 02.
Bengal :—						
Sone Canals: Patna Canal ...	65	65	57	78	80	71
Sone Canals: Arrah Canal ...	78	82	76	97	100	82
Sone Canals: Buxar Canal ...	72	89	77	87	113	91
United Provinces :—						
Upper Ganges Canal... ...	98	54	54	105	75	73
Lower Ganges Canal... ..	60	52	49	95	68	67
Eastern Jumna Canal ...	108	95	113	112	98	120
Punjab :—						
Western Jumna Canal ..	78	85	60	79	91	64
Bari Doab Canal . ..	73	92	78	74	99	86
Sirhind Canal	85	98	51	87	101	55
Chenab Canal	66	87	78	69	91	83
Bombay :—						
Nira Canal	76	139	112	84	153	115
Ojhar Canals	58	43	122	62	66	159

This table does not include Madras. In that Presidency the crops are divided into "first" crop and "second" crop, but the areas reported as irrigated under "first" crop represent the areas of land irrigated for the first time in the "*fasli*," which commences on July 1st and do not relate to the area irrigated during any particular period. The "first" crop also overlaps the "second" one, and the data on which any record of duty could be based are therefore confused and misleading, and it is not possible to give any useful information as to the duty of water from the Godavery and other large works in Madras.

It will be noticed in the foregoing table that there are, in many cases, large differences between the duties calculated "at the head" and on the "utilised" discharge. In the case of the Bengal Canals this is mainly due to the fact that a larger quantity of water is frequently run in the canals than is required for irrigation, with the object of scouring silt from the canals. The difference in the two duties is not necessarily any indication of waste or bad management.

The following table refers to the *rabi* crops, but is based on the discharge "utilised," and not on that *at the head*:—

DUTY IN RABI SEASON.

Province and Canal.	Number of Acres of Crop Matured by 1 Cubic Foot per Second of the "Utilised" Discharge.		
	1899—1900.	1900—01.	1901—02.
Bengal:—			
Sone Canals—Patna Canal	56	82	60
Sone Canals—Arrah Canal	85	112	120
Sone Canals—Buxar Canal	87	114	130
United Provinces:—			
Upper Ganges Canal	170	169	159
Lower Ganges Canal	198	199	191
Eastern Jumna Canal	237	172	196
Punjab:—			
Western Jumna Canal	141	98	115
Bari Doab Canal	164	149	221
Sirhind Canal	198	110	177
Chenab Canal	149	134	180
Bombay:—			
Nira Canal	106	118	113
Ojhar Canals...	115	85	121

These statements do not show the "base" of the duties, and they are consequently useless to determine the total volume of water actually used on the crop, but they are useful as a

DUTY OF WATER IN THE KHAREEF SEASON OF 1901.

Province and Canal	Average "Utilised" Discharge at the Head of the Canal during the Season.	B = Base, *i.e.*, Number of Days the Canal was in Flow.	D = Duty of Discharge "Utilised."	S = Equivalent Aggregate Depth of Water on the Fields on the Basis of the "Utilised" Discharge.	V = Volume "Utilised" per Acre Irrigated.
	Cubic Feet per Second.	Days.	Acres.	Inches.	Cubic Feet.
Bengal:—					
Sone Canals—Patna Canal ...	1,137	122	71	41	148,460
Sone Canals—Arrah Canal ...	1,197	122	82	35	128,550
Sone Canals—Buxar Canal ...	1,329	122	91	32	115,830
United Provinces:—					
Upper Ganges Canal ...	5,152	127	73	41	150,320
Lower Ganges Canal ...	3,133	141	67	50	181,830
Eastern Jumna Canal ...	1,310	169	120	33	121,680
Punjab:—					
Western Jumna Canal ...	4,200	181	64	67	244,350
Bari Doab Canal	4,382	182	86	50	182,840
Sirhind Canal	3,212	147	55	35	127,010
Chenab Canal	8,018	175	83	50	182,170

gauge of the area which a canal of a given capacity will irrigate effectively, and as a gauge of the area which can be efficiently irrigated from a given discharge, when all factors are considered. The statement on page 273 translates the *khareef* duties of certain canals for the year 1901 into a shape which is useful for various purposes. It is necessary to remember, however, that the depths of water and the volumes given in the two last columns do not represent the actual facts in the fields themselves. The figures give the depths and volumes which would have resulted if the "utilised" discharge had reached the fields.

The *khareef* crop in the United Provinces and the Punjab consists largely of maize, indigo, cotton and other crops, and only a small proportion of it is rice. In Bengal the

DEPTH OF WATER ABSORBED BY RICE CROPS.

Year.	Average Depth of Water due to— Rainfall.	Irrigation from the Canal.	Aggregate Total Depth of Water placed on the Rice Fields.
	Feet.	Feet.	Feet.
1893	2·89	2·14	5·03
1894	3·59	2·09	5·68
1895	2·33	3·02	5·35
1896	1·56	3·22	4·78
1897	3·29	2·37	5·66
1898	3·94	2·31	6·25
1899	3·12	2·14	5·26
1900	2·27	2·41	4·68
1901	1·88	2·81	4·69

khareef crop is almost entirely rice. The above figures are interesting as showing the amount of water which a rice crop will consume in Bengal. The figures are based on the

DUTY OF WATER IN THE RABI SEASON OF 1901—1902 IN UPPER INDIA.

Province and Canal.	Average "Utilised" Discharge at Head of the Canal during the Season.	Base = Number of Days the Canal was in Flow.	D = Duty of the Discharge "Utilised."	S = Equivalent Aggregate Depth of Water on the Field on the Basis of the "Utilised" Discharge.	V = Volume "Utilised" per Acre Irrigated.
United Provinces:—	Cubic Feet per Second.	Days.	Acres.	Inches.	Cubic Feet.
Upper Ganges Canal ...	4,290	182	159	27	98,900
Lower Ganges Canal ...	2,837	182	191	22	82,330
Agra Canal	1,219	182	135	32	116,480
Eastern Jumna Canal ...	1,252	170	196	21	74,940
Betwa Canal..	411	122	113	26	93,280
Punjab:—					
Western Jumna Canal ...	2,801	182	115	37	136,740
Bari Doab Canal	2,176	182	221	20	71,150
Sirhind Canal	3,119	182	177	24	88,840
Chenab Canal	6,009	182	180	24	87,360
Jhelum Canal	89	161	154	25	90,330

"utilised" discharge of the main canal, and they therefore exaggerate to some extent the actual depth of water which is placed on the fields by the canal. The figures refer to the Arrah Canal in Bengal and take cognisance of the months July to October inclusive.

The *rabi* crop in the Upper Provinces consists mainly of wheat, and is much more important than the *khareef* crop. The duties in the *rabi* season, given in the table at the foot of page 274, are in the same form as those for the *khareef* season on page 273. Similar figures for Bombay are, unfortunately, not available.

In the United Provinces and the Punjab the value of S varies from 20 to 30 inches in the *rabi* and in the *khareef* season from 35 to 60 inches. It cannot be too clearly stated that this is based on the "utilised" discharge, and is not the depth of water actually run into the fields (see page 271). It is noticeable that the volume used in Bengal in the *khareef* season is less per acre than that used in the Upper Provinces, a fact which, it is believed, is largely explained by the compact nature of the Bengal irrigation and the comparatively scattered positions of the fields in the other case.

But the great variation in duty which obtains, even on the oldest canals, is well illustrated by the following figures, which show the duties on the Bari Doab Canal in the month of November, for a period of ten years. The duties during this month are especially important, as November is the month in which the *rabi* sowings are principally made, and the duty which can be obtained in that month may determine the area of the crop which can be sown:—

STATEMENT SHOWING AVERAGE SUPPLY UTILIZED AND DUTY IN NOVEMBER ON THE BARI DOAB CANAL,

Year.	Rabi Area.	Average Supply Utilised during November.	Duty on November Supply.
1893—1894	337,504	3,046	111
1894—1895	326,087	2,911	112
1895—1896	342,078	2,369	144
1896—1897	384,388	2,231	172
1897—1898	464,217	2,624	177
1898—1899	427,439	2,047	209
1899—1900	375,614	1,871	201
1900—1901	412,143	2,776	148
1901—1902	480,794	2,434	198
1902—1903	453,010	2,043	222
Average of ten years	400,327	2,435	169

It will be seen that the "duty" of 1 cubic foot a second varies from 111 to 222 acres, and that the average was 169 acres. It has been recently decided to adopt 160 acres to the cubic foot per second as the full supply factor on the Bari Doab Canal in the *rabi* season. The factor of 150 had been used, but it has been proved to be too small. Thus, if a distributary is expected to irrigate 8,000 acres annually, it would be given a full supply of 50 cubic feet per second. In the case of distributaries which run during the *khareef* season only, the factor is taken at 70 acres per cubic foot per second.

The duty of the water drawn in at the head of a system is a useful factor in many ways, but it is often most desirable to gauge it at other points in the system, and with reference to different "bases," that is, to shorter periods of time, than that of the whole irrigating period of a crop:

for the duty based on the discharge drawn from the source of the supply on the average of the whole season, fails to take cognisance of fluctuating demands. It is necessary in most cases to know not only the average discharge of a season, but the maximum discharge required at a period of pressure during the season.

In the United Provinces statistical tables used to be prepared annually showing the duty of the water in the distributaries. But they have been discontinued of late years. These duties were calculated with reference to the discharge at the head of the distributaries, and so

		Upper Ganges Canal	Lower Ganges Canal.	Agra Canal.	Eastern Jumna Canal.
		Acres	Acres.	Acres.	Acres.
Duty of the canal on its "discharge at head"	Khareef	69	44	82	111
	Rabi	164	139	127	183
Duty of the canal on its "utilised" discharge	Khareef	74	64	103	113
	Rabi	173	187	132	189
Duty of the distributaries on their "discharge at head"...	Khareef	91	65	103	127
	Rabi	215	216	132	216
		Days.	Days	Days.	Days.
Base of the above duties	Khareef	122	122	106	180
	Rabi	179	179	172	171
		Inches.	Inches	Inches.	Inches.
Depth of water (measured at the distributary head) used per acre ...	Khareef	32	44	24	34
	Rabi	20	20	31	19

all loss by escapes, leakage, and all other causes between the river and the distributary were eliminated. The above table shows the duties obtained on the four principal canals in the United Provinces in the year, 1899.

The duties in the distributaries in the above table show, in all but one case, better results than the duties in the canal, because the water in the distributaries is not subjected to many of the causes of loss which affect the supply in the main canal: if the duties had been gauged—as they sometimes are in individual cases—at the outlet from the distributary into the village channel, the duties obtained would have been still higher, and the volume of water actually passed on to the fields would have been less—probably 20 per cent. less—than this statement shows. The results given in the preceding table were obtained on canals which have been many years in operation; the irrigation is well developed and the administration thoroughly organised.

The duty of water on the supply "utilised" of the principal canals in the Punjab is given, in the following table, for eight years. Generally speaking the figures show an increase in the duties, especially in the case of the Chenab Canal, which is comparatively new. The great variation in the duties is a caution to engineers, who may be designing new canals, not to be too sanguine in estimating the area which a given volume is likely to irrigate.

The loss of water between the head of a canal and the head of the distributaries frequently varies from 20 to 40 per cent. The variation of the duties of individual distributaries, even of the same group, is often very marked. Thus, in the case of fifteen distributaries in the Meerut division of the Ganges Canal, which had an average duty of 105 acres during one khareef season, it was found that the duties of individual distributaries varied from 80 to 126 acres. And the divergence may be much greater. For instance, the Sakla distributary in the Sone Canals in

Bengal, which irrigates lands which are for the most part clay, was gauged, one khareef season, as working to a duty of 115 acres to the cubic foot, while the Kaithee distributary, close by, but which ran in sandy soil, attained at the same time to a duty of 67 acres only.

		1894-95	1895-96.	1896-97.	1897-98.	1898-99.	1899-1900.	1900-1901.	1901-1902.
		Acres	Acres.	Acres.	Acres	Acres.	Acres.	Acres.	Acres.
Western Jumna Canal ...	Khareef	83	70	104	111	80	79	91	64
	Rabi	62	146	152	140	162	141	98	115
Bari Doab Canal ...	Khareef	70	68	73	82	77	74	99	86
	Rabi	112	135	139	170	162	164	149	221
Sirhind Canal	Khareef	20	44	78	93	66	87	101	55
	Rabi	77	156	197	164	182	198	110	177
Chenab Canal	Khareef	51	66	83	80	67	69	91	83
	Rabi	81	98	89	106	117	149	134	180

In 1901 the "utilised" discharge of the Upper Ganges Canal, taken as a whole, was equivalent to 41 inches of water in the fields in the *khareef* season and 27 inches in the *rabi* season. The following table shows the corresponding depths of different groups of distributaries, aggregating in all about 2,600 miles, in the same year:—

Canal Division.	Depth of Water used.	
	Khareef.	Rabi.
	Inches.	Inches.
Northern	35	18
Anupshahr	29	30
Meerut	32	20
Bulandshahr	31	22
Aligarh	32	18
Average of all Distributaries	32	20

This shows that between 20 and 30 per cent. of the water "utilised" in the whole system did not reach the distributaries at all. The Chenab Canal in the Punjab irrigates the largest *rabi* area of any canal in India. During the three years ending March, 1904, the average *rabi* area irrigated[1] was 1,155,685 acres, and the average discharge of the canal, taken, not at the head of the canal, but *at the heads of the distributaries*, was 5,546 cubic feet per second. This gives a duty of 208 acres per cubic foot per second at the heads of the distributaries. The Bari Doab Canal, which is an old canal, gave for the five years ending March, 1904, an average *rabi* duty, taken on the discharge *at the heads of the distributaries*, of 263 acres. These are high duties, and it must be remembered that they are averages, and are not a test of the maximum duty to be obtained in times of pressure, which would be smaller.

[1] Page 28 of Mr. Benton's "Report on the Upper Jhelum and Chenab and Lower Bari Doab Canals," 1904.

The tables which have been given in this chapter show the great variation which occurs in duties in different canals and in different parts of the same canal system. They show that the duty of a cubic foot of water "utilised," in the *khareef* season, may vary from 50 to 150 acres, and in the *rabi* season from 30 to 230 acres, and that, when the "base" of these duties is taken into account, the volume of the discharge "utilised" which is necessary to mature a *khareef* crop appears to vary from below 100,000 to above 300,000 cubic feet, and in the *rabi* crop from about 35,000 to as much as 250,000 cubic feet. It may be thought that such widely divergent results can be of little value. Such divergence is, however, to be expected from the nature of the case, and the results obtained are chiefly valuable as a record of what may be expected in cases where the circumstances are similar, and as a warning against too sanguine anticipations. But duties are not only valuable in judging of the probable results in any project which is under review, but also in comparing the efficiency of the canal management in a running canal, on which the duties are worked out, for a series of years, on one regular plan. It must be admitted, however, that an intimate acquaintance with the circumstances is essential to enable an observer to draw a sound conclusion. For instance, on the Jamda Canal in Bombay, where nearly half the total area under irrigation in the *rabi* season is wheat, the duty of one season was 32·4 acres per cubic feet per second to a base of 92 days on the "utilised" discharge. This is equivalent to 245,330 cubic feet in volume per acre irrigated. This was the volume, it must be remembered, which was taken from the source of supply after making deductions for actual gauged losses. But experiments were conducted on this canal by gauging the discharge actually run on to the fields of wheat in two cases, and it was found that the duty of the water *at the field*, to the same base of 92 days, was 86 acres in one case and 126 acres in the other, corresponding to volumes of 91,704 and 62,725 cubic feet per acre, which are reasonable quantities of water (25 inches and 17 inches respectively) for a wheat crop. The right conclusion to be drawn from the extremely low duty of the canal generally was, that very large quantities of water were lost or wasted between the head-sluice and the fields. This is a result which is not uncommon in Bombay, where the water is often led for considerable distances from the source of supply, along shallow channels to irrigate fields scattered widely over the district, and this is the chief explanation of the very low duties which are obtained in that province. In the Hathmati Canal, for instance, it is stated that 50 per cent. of the supply is lost by absorption and evaporation in the first 10 miles. Irrigation under such conditions must be wasteful of water.

In all cases it is very important to ascertain the duty of water in periods of pressure; especially where, as in Bengal and Madras, the area under irrigation during a season is almost entirely one kind of crop. In those provinces the *khareef* crop is practically all rice. In the United Provinces and the Punjab it consists of indigo, cotton, and rice. Where there are several different kinds of crops grown in the same season the available supply of water can be more equally distributed, and there is not the same intensity of demand at the same moment. With reference to this point, the actual necessities of the crops is not the only factor to be considered, but, not unfrequently, the customs and prejudices of the people have to be reckoned with. This is exemplified in the case of the Sone Canals in Bengal. The *khareef* crop is almost entirely rice. The people had been accustomed for centuries, before the canals were made, to mature the crop entirely from the local rainfall; in good years the crop did well, in bad years it almost entirely failed. To a certain but small extent the crop was irrigated from small tanks in which the local rainfall was impounded. The rainfall of the monsoon is divided by the people into *nechutras*, or periods which are regularly fixed by the phases of the moon. They have become accustomed to consider water necessary during the particular periods at which they reckoned that the rain

generally fell, and above all things they considered it essential that the rice should be copiously supplied with water during the ten or twelve days of the "Hathia" *necluttra* in October. To a considerable extent, no doubt, the supply of a copious volume of water at this time is really essential to the crop from a purely agricultural point of view, but it is probably not essential that this copious supply should be all delivered on the fields within one particular period of about ten or twelve days. But here the custom or prejudice of the people is a force. They drain off their fields to a considerable extent before the "Hathia" in anticipation of a heavy rainfall, and if the "Hathia" rain fails, the demand becomes most intense and a strain is placed, for rather less than a fortnight, on the canals, which taxes every part of the system. So much is this the case that the irrigation officers limit the area which they will undertake to irrigate, not by the duty of the water based on the results of the working of the entire season, but on the duty of the water based on the area which can be watered in about twelve days. The duties which have actually been obtained on the discharge at head of these canals during these periods of extreme pressure have varied from 45 to 50 acres per cubic foot per second, and it may be said that, until the people can be educated to extend the period during which they require so copious a supply in so short a time, the area of rice which can be irrigated by these canals must be restricted to that due to a duty of about 50 acres on the maximum discharge. It will be seen from the lower table on page 273 that the duties, calculated to the base of the whole season on the "utilised" discharge, varied in 1901 from 71 to 91 acres; in this case, these duties, though accurate in themselves, are insufficient to gauge the area which it is possible to irrigate from a channel of a given capacity. A duty of 45 acres to a base of ten days is equivalent to a depth of 5·3 inches on the fields if the entire supply "utilised" reached them, and it is certain that in the Sone Canals, during a period of pressure, a very large proportion—probably at least 70 per cent.—does reach the fields. This has been checked, to some extent, by experiments recorded on the fields themselves; it was found that a discharge of 1·26 cubic feet a second, running for 10 days 8 hours and 47 minutes, fully irrigated—according to the views of the cultivators—an area of 80 acres. This is equivalent to a depth of almost exactly 4 inches in the fields. This, in itself, is a reasonable amount of water to be required during ten days, but the difficulty is due to the fact that it is during the same ten days of the "Hathia" that this demand occurs. Every cultivator wants the water at the same time. In Madras, where the irrigation is also almost entirely confined to rice, it is the general rule that the duty of water in large channels may be taken as 66 acres to the cubic foot for any base: this duty is about 50 per cent. greater than that which can at present be realised on the Sone Canals if the needs and the customs of the people are satisfied.

In the case of storage works in Madras, irrigating rice lands in their immediate vicinity, it is considered necessary to allow 200,000 cubic feet of water to each acre irrigated for the entire season: this is equivalent to a duty of 80 acres to the cubic foot to a base of 185 days. In Mysore it is usually assumed that 2,61,360 cubic feet (one Mysore "unit") of capacity of tank is necessary for the irrigation of one acre of rice land.

In the case of irrigation in the *rabi* season, the demand for water is subject, of course, to great variations; but, as the crops are more varied and at different stages of maturity, a simultaneous demand for water for all the crops is rare, and is spread over a longer period than in the case just mentioned. It will be seen, from the statements given above, that the variations in *rabi* duty are even greater and more perplexing than those for the *khareef* season, even when the different "bases" are allowed full weight. To a very large extent these great differences are to be read as warnings of the impossibility of effecting economical irrigation over widely scattered patches of cultivation. The low duties are mainly due to large losses between the head of supply and the

fields.[1] Thus the duty for the *rabi* crop on the Nira Canal in Bombay, where the channels are long and irrigation is scattered, is as little as 95·4 acres, but the duty which was realised in five distributaries of the canal, reduced to the same base of 92 days, was 123 acres, which is equivalent to a volume of 64,170 cubic feet per acre, as compared with 83,320 admitted at the head of the canal, or a loss of nearly one-fourth of the supply. On an irrigation system, which actually irrigates a large proportion of the area under command, duties of 120 to 180 acres to a base of 150 days (equivalent to 108,000 and 72,000 cubic feet per acre) on the discharge "utilised" can be obtained without difficulty. And, in selected distributaries, duties of 200 to 250 acres (64,800 and 51,840 cubic feet per acre) are not uncommon to bases of 100 days or more. But it is probable that, in periods of pressure, higher duties than 100 acres to a base of 15 days cannot be expected on the discharge "utilised" in an extended system of canals. This is equivalent to the statement that the whole area of a *rabi* crop under irrigation may, in times of great pressure, demand a "utilised" discharge at the head of the system of 12,960 cubic feet in 15 days per acre, which (if the whole supply reaches the field) is equivalent to 3·57 inches in depth. This, in ordinary cases, where the loss from absorption, evaporation, and other causes was moderate, might result in an actual depth of water delivered in the field of 2 to 2½ inches. The depth given by irrigation from wells rarely exceeds that amount.

In the Bombay Presidency careful experiments were made to determine the quantity of water actually used in the fields for different crops. The experiments do not state the nature of the soil in which the various crops were grown; but the variation in quantity of water used was due, no doubt, partly to the different soils. Rectangular gauge boards were erected in the channel close to the fields under irrigation; so that the quantities of water indicated are those which actually passed on to the fields. The following statement gives the results :—

VOLUMES OF WATER CONSUMED AT THE FIELD IN BOMBAY.

Name of Work	Volumes in Cubic Feet used in Maturing the Crops named.				
	Rice	Wheat	Sweet Potatoes	Ground-nut.	Sugar-cane.
Mhasvad Tank...	—	57,400	49,257 68,251	86,121	
Lower Panjhrah Works	—	90,830			
Ekruk Tank	192,550	106,790 45,364 42,800 54,740	—	82,170	479,000
Jamda Canal	—	33,463 91,704 62,725			
Krishna Canal	—	—	240,000	—	337,000
Nira Canal	—	55,641 136,162 70,501 106,060			

The average of the observations on wheat gives 73,400 cubic feet per acre, or 20 inches in aggregate depth on the field. This is certainly more than would actually be used in some soils, where three or four waterings of 2½ inches on the field are sufficient. In the case of a

[1] See Chapter IV., on Absorption.

reservoir project in Baluchistan it was assumed that 55,000 cubic feet of water was sufficient for a wheat crop: but this figure is a low one. Mr. Allan Wilson[1] gave the quantity of water required to mature a crop as 94,500 cubic feet for rice, 35,100 cubic feet for wheat and other grains, and 216,000 for sugar-cane, but these figures also seem to be too low. Experiments made recently on the Mutha Canals show that the quantity of water required, at the field, for an acre of sugar-cane is between 8,000 and 10,000 cubic feet for one watering if waterings are given once in ten days. In Rajputana an allowance of 100,000 cubic feet per acre is considered sufficient, and this includes losses by evaporation and absorption.

The duty of water in Egypt is usually stated in terms of the number of cubic metres of water required in twenty-four hours for each *feddan* (a *feddan* is practically the same as an acre), but in the case of "basins" the quantity of water needed is that which will give an effective depth of about one metre over the area in the time available, which is about 40 days: this, after making some allowance for loss, is equivalent to a discharge of from 100 to 125 cubic metres a day per acre (4,047 square metres), which may be expressed in the ordinary Indian notation as a duty of about 25 to 20 acres per cubic foot a second to a base of 40 days. The lands in the basins grow *shitwi*, or cold-weather crops, in December, January, and February, on the moisture accumulated in the ground during the inundation. In those cases where *shitwi* crops, which consist of beans, wheat, barley, lentils, and pulses, are grown on lands which are not "basin" lands and are directly irrigated during the season, the quantity of water required, during the period of the maximum rate of supply, varies from 10 to 22 cubic metres per acre per day, which, in the Indian way, would be expressed as a duty varying from 250 to 120 acres to the cubic foot, and corresponds with the rabi duty. The *nili* crop of Egypt, which is grown in August, September, October, and November, consists chiefly of Indian corn, and the duty, during the period of maximum supply, is taken at 25 cubic metres in twenty-four hours per acre, which is equivalent to a duty of 100 acres to the cubic foot. The *sefi*, or hot-weather crops, which are irrigated in April, May, June, and July, consist of cotton, rice, vegetables, summer maize, and sugar-cane. The quantity of water required is taken as 40 to 50 cubic metres per day per acre for rice, which is equivalent to a duty of 60 to 50 acres per cubic foot per second. For the other crops 20 to 25 cubic metres per acre per day is taken: this is equivalent to a duty of 122 to 98 acres per cubic foot per second. In Upper Egypt, where the heat and evaporation are greater, 25 to 33 per cent. more water is required to mature a crop.

Mr. Herbert Wilson, in his "Manual of Irrigation Engineering," gives the following interesting table of duties based on the supply entering the canal head:—

Locality.	Duty in Acres per Cubic Foot per Second.	Locality.	Duty in Acres per Cubic Foot per Second.
Northern India	60—150	Idaho	60—80
Italy	65—70	New Mexico	60—80
Colorado	80—120	Southern Arizona	100—150
Utah	60—120	San Joaquin Valley, California ...	100—150
Montana	80—100	South California, Surface Irrigation	150—300
Wyoming	70—90	" Sub-Irrigation ...	300—500

Sir William Willcocks[2] considered that 200,000 to 250,000 cubic feet of storage capacity in reservoirs was necessary for perennial irrigation in South Africa; this, if two crops are raised,

1 "Proceedings of the Institution of Civil Engineers," No. 1193, April, 1868.
2 Report on Irrigation in South Africa by Sir William Willcocks, 1901.

is at least equivalent to 24 inches in depth on the field, calculated on the discharge drawn from the reservoir.

For the proper determination of duties it is important to organise a regular system of gauging canals, branch canals, and distributaries at stated intervals, and to keep daily records of the discharges of all distributaries. Main canals are generally gauged daily by velocity-rods or floats: smaller canals and distributaries are occasionally gauged in the same way in order to check the daily discharges, which are recorded either from the calculated discharge of the head-sluice or by the discharge known to be due to a given depth in the first reach.

The area of crops which can be efficiently irrigated by a given quantity of water is increased by skill in the distribution of the available supply: this skill is required no less in the actual cultivator of the field than in the engineer who controls the discharge of the various channels which are under his care. There are only a few crops which require water more than three or four (possibly five) times during their growth. Say that four waterings are required in a season of twenty weeks: it is obvious that the quantity of water required at any one moment will be reduced to a minimum if the irrigation proceeds with daily uniformity: that is, if the whole crop is irrigated once in five weeks and $\frac{1}{5}$ of the crop is irrigated in one week and $\frac{1}{35}$ of it every day. Further, since the loss from evaporation, absorption, &c., is more or less in proportion to the length of channel in flow, and is increased when the channels are running in low supply, it is economical to carry out the irrigation by a system of rotation under which the minimum length of channel is in flow at one time: and, since it is considered that there is more loss in village channels and field channels than in other parts of a system, it is an economy of water to restrict to the utmost the time during which any particular village channel is in flow. The most wasteful system of irrigation possible is that under which all branch canals, distributaries, and village channels are in use continuously and the available supply is slowly dribbling into the fields. For, not only is the actual loss of water greater, but under this system there is also this further disadvantage, that the velocities in all the distributaries and minor channels are reduced and the silt in the water, which at these points of the system is nearly always advantageous to the fields, is largely deposited in the channels, and not carried on to the cultivated ground. The system of irrigation by rotation, or by *tatils*, as it is called in Upper India, is of great advantage, not only in checking the loss of water in the channels, but in teaching economical irrigation to the cultivators, and in ensuring an equitable division of the supply among the people. One arrangement of *tatils* is that in which all distributaries and the larger channels which supply them are kept in continuous flow, and the outlets supplying the village channels are "tatiled," that is, closed by rotation, in convenient groups for a certain number of days at a time. But such closures are a constant source of friction between the cultivators and the canal establishment; they offer great temptations to the subordinate officials, and the enforcement of them involves great labour on the staff. On the Upper Ganges Canal the necessity of *tatils* of the outlets themselves has been almost entirely abolished, and on many of the other canals in the United Provinces the *tatils* on many of the distributary channels have also been abolished, with results which are said to be beneficial. This result has largely been brought about by the construction of new minor channels, by proportioning the size of the outlets to the areas they have to irrigate, and by readjusting the waterway and slope of the distributaries to suit the discharges. But such arrangements are not always advantageous, and it is generally economical to enforce *tatils* of distributaries, one group being closed for a time entirely, while other groups take the entire discharge of the canal, these being in their turn closed for a fixed period. In some cases *tatils* are enforced both on groups of distributaries, and then again on groups of outlets on those distributaries: but this needs not only great skill in arrangement, but great

experience and practice on the part of all concerned, to make it a success. It is not often that *tatils* are extended to branch canals, except, perhaps, to the extent that the supply of one branch may be restricted, and that of another increased correspondingly, at stated times: if this is done, the *tatil* on the distributaries and outlets on each of the branches has to be adjusted accordingly. *Tatils* increase the efficiency of irrigation by enabling the engineers to distribute the supply available over a larger area: if they were not enforced, the cultivators near the heads of channels in flow might, and sometimes do, absorb all the supply. Where there is an abundant supply, in channels of sufficient capacity, *tatils* are unnecessary. As the available supply becomes—say in a year of deficient flow in the river from which the canal is drawn—more and more restricted, there is greater necessity for the strict administration of *tatils;* and not only so, but it sometimes becomes necessary to alter the arrangement of the closures with reference to the quantity of water available; for, as the supply diminishes, it is not possible to keep the same number of channels in efficient flow, consequently the number has to be reduced and the *tatils* or closures increased in time. It thus occurs that, in some canals where *tatils* have been worked for a series of years, and experience has been gained and discipline established among the cultivators, there are regular tables showing the different arrangements of the closures for certain specified discharges of canals.

"TATIL" TABLE No. 1.

Days of the Week.	Distributary V.	Distributary W.	Distributary X.	Distributary Y.	Distributary Z.	Draught on the Canal each Day.
Full supplies carried =	95	105	85	70	95	Cubic Ft.
F.				+		380
Sat.				+		380
S.				+		380
M.				+		380
T.	+					355
W.	+					355
Th.	+					355
F.	+					355
Sat.					+	355
S.					+	355
M		+				345
T.		+				345
W.		+				345
Th.		+				345
F.				+		380
Sat.				+		380
S.				+		380
M.				+		380
T.	+					355
W.	+					355
Th.	+					355
F.	+					355
Sat.					+	355
S.					+	355
M.		+				345
T.		+				345
W.		+				345
Th.		+				345

In the simplest cases, where only the outlets from the distributaries are *tatiled*, it is usual to divide the distributary into three lengths, so that the village channels taking off each length command areas which are approximately equal. The outlets in the first length of the distributary usually get water for three days in each week, and are closed for four days: the outlets in the second length of distributary are open on the four days when those in the first length are closed, and closed on the three days when the others are open: in the third length of the distributary the outlets to the village channels are allowed to be open all the week as a rule, and they absorb all the water passed on by the upper lengths. Tables are prepared showing the particular days of the week when certain outlets are allowed to be opened. Simple as this system appears to be, it may take years of patient perseverance to thoroughly establish it.

When more complicated *tatils* are arranged, and closures are enforced on whole distributaries as well as on the outlets taken off certain lengths of them, it is necessary to consider longer periods of time than a week. Fortnightly or even monthly periods have to be worked out. The tables on this and the next page were

"TATIL" TABLE No. II.

—	Friday	Saturday.	Sunday.	Monday.	Tuesday.	Wednesday.	Thursday.	Friday.	Saturday.	Sunday.	Monday.	Tuesday	Wednesday.	Thursday.	Friday.	Saturday.	Sunday.	Monday.	Tuesday.	Wednesday.	Thursday.	Friday.	Saturday.	Sunday.	Monday.	Tuesday	Wednesday.	Thursday.
DISTRIBUTARY V...					+	+	+	+											+	+	+	+						
Section *v* 1						+	+	+	+	+	+	+	+						+	+	+	+	+	+	+	+	+	
,, *v* 2	+	+	+	+	+	+	+	+						+	+	+	+	+	+	+	+	+						+
,, *v* 3					+	+	+	+	+	+	+	+	+						+	+	+	+	+	+	+	+	+	
Branch Distributary C					+	+	+	+											+	+	+	+						
Section *c* 1	+	+	+	+	+	+	+	+						+	+	+	+	+	+	+	+	+						+
,, *c* 2					+	+	+	+	+	+	+	+	+						+	+	+	+	+	+	+	+	+	
,, *c* 3	+	+	+	+	+	+	+	+						+	+	+	+	+	+	+	+	+						+
,, *c* 4					+	+	+	+											+	+	+	+						
Branch Distributary A					+	+	+	+											+	+	+	+						
Section *a* 1	+	+	+	+	+	+	+	+						+	+	+	+	+	+	+	+	+						+
,, *a* 2					+	+	+	+											+	+	+	+						
Branch Distributary B					+	+	+	+											+	+	+	+						
Section *b* 1					+	+	+	+	+	+	+	+	+						+	+	+	+	+	+	+	+	+	
,, *b* 2					+	+	+	+											+	+	+	+						
DISTRIBUTARY W...											+	+	+	+											+	+	+	+
Section *w* 1	+	+	+	+	+						+	+	+	+	+	+	+	+	+						+	+	+	+
,, *w* 2						+	+	+	+	+	+	+	+	+						+	+	+	+	+	+	+	+	+
Branch Distributary D											+	+	+	+											+	+	+	+
Section *d* 1	+	+	+	+	+						+	+	+	+	+	+	+	+	+						+	+	+	+
,, *d* 2						+	+	+	+	+	+	+	+	+						+	+	+	+	+	+	+	+	+
Branch Distributary E											+	+	+	+											+	+	+	+
Section *e* 1	+	+	+	+	+						+	+	+	+	+	+	+	+	+						+	+	+	+
,, *e* 2						+	+	+	+	+	+	+	+	+						+	+	+	+	+	+	+	+	+
,, *e* 3											+	+	+	+											+	+	+	+
Branch Distributary F											+	+	+	+											+	+	+	+
Section *f* 1	+	+	+	+	+						+	+	+	+	+	+	+	+	+						+	+	+	+
,, *f* 2						+	+	+	+	+	+	+	+	+						+	+	+	+	+	+	+	+	+

in use in a case where a discharge of about 360 cubic feet a second (but which varied from 345 to 380, in fact) was allotted for distribution among a group of five distributaries named V, W, X, Y, and Z, taking off a branch canal. The discharge is first divided among the distributaries according to the areas which have to be irrigated in each, so as to ensure as far as possible a regular draught of 360 feet on the canal. The table on page 283 shows the days of closure of each distributary: the head-sluice is entirely closed on those days when the square in front of it contains a +, and open when it is blank.

Distributary X is open all through the month; distributary V is closed every alternate week from Tuesday to Friday inclusive, and the other distributaries as they are marked.

The diagram on this page shows the working of the *tatil* on the first four days, distributary Y being closed entirely throughout. The dotted lines show the village channels which are in flow, the thin continuous lines show the village channels which are closed (these channels are only shown from one of the five distributaries, in order to avoid confusion). The thick black portions of the distributaries are those portions which may be in flow themselves, but from which all outlets to village channels are closed. Thus distributary W is in flow and so are the three branch distributaries taking off from it, although the first sections of all are black, showing that, on the four days to which the diagram applies, the village channels from those sections are closed at their heads.

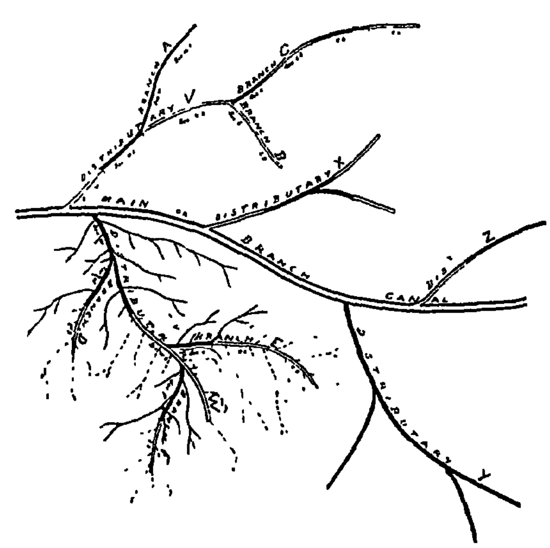


DIAGRAM ILLUSTRATING TATILS.

When the *tatils* of the distributaries have been arranged in Table I., Table II. has to be worked out for each section. The sections are mapped out in convenient groups of outlets, and the days when each section can take water are arranged, the crossed squares showing the days when the outlets are closed. For instance, on distributary V it will be seen from Table II. that the outlets on sections *v* 1, *v* 3, *c* 2, *c* 4, *a* 2, *b* 1, *b* 2, are open, and the others closed for the first four days (Friday to Monday inclusive): while on distributary W the outlets on the sections *w* 1, *d* 1, *e* 1, and *f* 1, are closed and the others open, distributary Y being closed altogether. Then, for the next four days (Tuesday to Friday inclusive), distributary V is closed altogether and another arrangement comes into force, Y being opened and its various sections tatiled. Table II. on the preceding page is only worked out for two of the five distributaries shown in Tatil Table No. I., page 283, and in the diagram on this page, but it is sufficient to show the system which is employed.

CHAPTER XVI.

THE ALIGNMENT OF CANALS AND DISTRIBUTARIES.—DESIGN OF CHANNELS.

Alignment of Canals on the Watershed—Contoured Plan of the Irrigable Area—Velocity to be allowed in Canals—Dimensions of Canals—Restriction of Irrigated Area—Best forms of Channel—Canals in Side-long Ground—Retaining Walls in Kurnool Canal Banks—Cost of Main and Branch Canals—Design of Distributaries—Discharging Capacity of Distributaries—Silt Berms in Distributary Channels—Rules for the Preparation of Distributary Designs—Difficulties connected with Minor Channels for Rice-fields—Cost of Distributaries per Mile and per Acre Irrigable—Outlets from Distributaries—Regulation of the Size of Outlets—Drainage of Irrigated Tracts—Cost of Drainage Works.

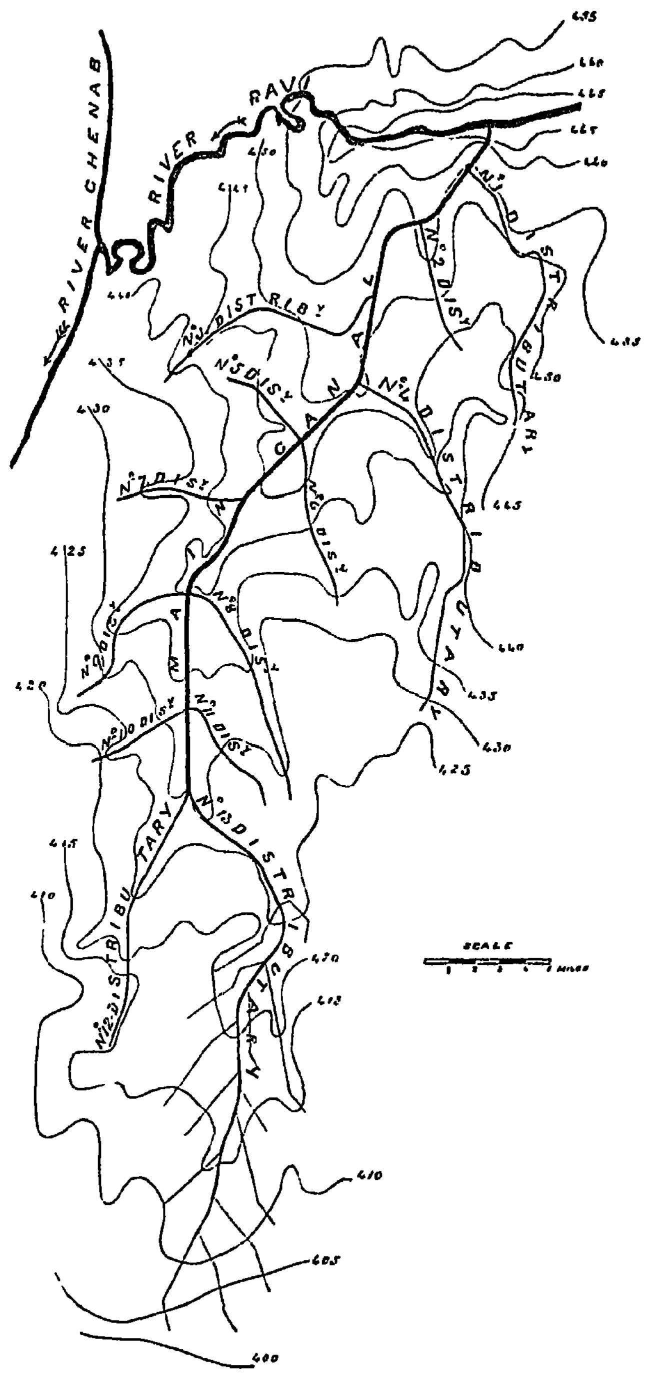
THE point of first importance in the alignment of the channels of an irrigation system is that all of them should, as far as may be possible, run on the watershed. In that position they both avoid interference with drainage and hold command over the country: an ideal irrigation system would have no cross-drainage works. But it rarely occurs that the physical features of a tract over which irrigation can be extended conform themselves so exactly to the requirements of the engineer, and, in almost all cases, the alignment of a main canal has to be determined by a balance of many considerations. One of the most weighty of these, of course, is the best position for the head-works: if there are several possible sites for these, the alignment of the canal in its upper reaches is primarily determined by the cost of the head-works and of the different routes which are possible. The highest site for the head-works may involve less depth of cutting in the canal, but a longer channel: or it may necessitate crossing heavy torrents or drainages which can be avoided by a lower head: or it may require that the canal should be carried through an unculturable country for a long distance before the fertile land is reached. The first reach of any canal drawn from a river is always unprofitable in itself, as it is necessarily in cutting, and little or no irrigation from it is possible. The problem to be solved in connection with it is the cheapest route by which it can be constructed, so as to deliver the water on the surface of the ground at a point where the canal can be carried along a main watershed of the tract to be irrigated. There are, of course, cases, such as that of a canal leading from a reservoir in hilly ground, or of one on the upper margin of a deltaic tract, in which the alignment of the canal must necessarily follow a contour—or very nearly follow it—along the foot of the hilly ground. In such a case the alignment may be said to be marked out by Nature: but in most other cases there is room for much skill and judgment in selecting the line for the first few miles of any system.

A contoured plan of the country to be irrigated is of great assistance in determining the alignment both of main canals and of branches, distributaries, &c. Parallel lines of levels, generally about half a mile apart (on the Chenab Canal they were only 550 feet apart), are run over the whole country to be dealt with, and the contours at any convenient vertical distance apart—usually 5 feet—are marked on it as shown in the sketch on the opposite page.

In this case the ridges and drainages of the country are shown clearly by the contours: the advancing loops indicating the ridges, the retiring loops the drainages. It will be noticed that there is a ridge which commences on the bank of the river Ravi some 6 miles below the head of the canal, and is well marked by the contours throughout: the canal does not follow this in the first few miles, but is carried on to it at about the point where it cuts contour 450: the

alignment of the first reach is, of course, in less cutting than it would have been had the canal followed strictly on the ridge, and, as the head is higher up the river, a better command is obtained. The distributaries should be aligned, with at least as much care as the larger channels, on the ridges if possible; and, where circumstances do not permit of this, the alignment should be at right angles to the contours, that is, parallel to the general slope of the tract to be irrigated by the distributary. In the example given in the sketch, Nos. 7, 8, 9, 12, and 13 run on well-marked ridges; Nos. 1 and 4 cross depressions in their course; and the others are more or less at right angles to the contours. The same principles are observed in aligning the minor channels, or village channels as they are often called, which draw their supply from outlets in the distributaries. These channels are shown in the case of No. 13 distributary in the example given. Before laying out a system of distributaries it is an immense advantage to survey the drainages independently, and to mark them out on the contoured map: this prevents any confusion arising with reference to the true watersheds.

The history of the distributaries on the Ganges Canal in the United Provinces is instructive as illustrating the importance of the correct alignment of all irrigation channels.[1] As originally designed, the distributaries did not follow the minor watersheds, and, consequently, interfered considerably with the natural drainage of the country. The slope given was too great and the capacity of the channels, did not allow of *tatils*. They have now been re-aligned to a large extent, or, where this was found to involve too great an interference with existing irrigation, culverts have been built at all drainage crossings. Where the old distributaries were in high embankments, the outlets have been removed, and the irrigation is effected by minor channels taking out from the main distributary in higher ground.



CONTOUR PLAN, SIDHNAI CANAL.

Many of the distributary channels on the Ganges Canal have been remodelled of recent years, so as to enable them to run every alternate week, instead of continuously, as they formerly did. Larger outlets have been given to enable the cultivators to irrigate their fields more

[1] Note by Mr. Hutton, Superintending Engineer.

expeditiously. Considerable economy of water has resulted from this introduction of *tatils* of the distributaries, as it has not only taught the cultivators to be more careful of the water, but the waste of water running continuously in the village channels, even when not required, is obviated.

The slopes of the channels, too, have been flattened: the usual slopes now given are 1·6 feet per mile for the first mile or so, and after that the slopes are reduced to 0·8 feet, or even as low as 0·56 feet per mile, except where the water contains heavy silt. This reduction of the slope has necessitated the construction of a number of small falls, which are of the notch type. The advantages of this reduction of slope have been found to be; first, that the channels are no longer eroded by the stream, the velocity is so reduced that a thin layer of clayey silt is deposited on the wetted perimeter of the channel, which considerably reduces loss by percolation; and, secondly, that an unduly high water surface is avoided. The level of the water is made to conform more nearly to the contour of the slope, so that the necessity for high embankments, with consequent loss by percolation, is in a large measure obviated.

As a result of Mr. K. G. Kennedy's[1] investigation into the cause of silting of channels, great attention is now paid by the engineers of the Ganges Canal to the relation between the bed width and depth of full supply in distributaries. A much greater ratio is now given than used to be allowed. Distributary channels which take off from a canal which carries heavy silt are now usually designed in the head reach so that the ratio of full supply depth to bed width is as 1 to 4. Below the head reach, a ratio of 1 to 3 is generally given, partly for the reason that fluctuation in the supply does not so much affect the head on the outlets as when this ratio is less.

The results of remodelling the Ganges Canal distributaries are—(1) greater regularity of supply in all reaches of the channels; (2) greater economy in the use and distribution of water; and (3) the abolition of the periodic closures of irrigating outlets, which in former days was the cause of so much friction between the canal establishment and the cultivators; and (4) a large saving in the cost of silt clearance.

The main points to be considered in designing the various channels of an irrigation system are —(1) the velocity of flow which can be allowed; and (2) the quantity of water which has to be passed down them. With reference to the first point, consideration has to be given to the question of silt deposit, of the scour of the banks, and, if the canal is to be navigable, of the impediment to traffic. It is usually considered in India that a higher velocity than 2 feet a second, 1⅓ miles an hour, is undesirable in a navigable canal, and a velocity of 2½ feet a second is a marked impediment to boats towed by men or animals. If the canal is not to be navigable, the most economical velocity, as regards the size of the channels, is, of course, the highest one which the soil will stand. On the other hand, a low velocity, with, consequently, a low surface slope, will shorten the length of the upper reach of the canal, and bring the water more quickly on to the surface of the ground. But low surface slopes and low velocities mean larger channels, and, if the river carries silt, larger silt deposits in the canal head. Here all the matters concerning silt which have been discussed in Chapter III. require consideration. As a general rule the highest velocity which the soil can stand without erosion will be found the most suitable in all parts of a canal system, and, in the first reach of a canal, it is not infrequently desirable to give the canal a slope which will cause a velocity greater than the banks will stand, and to revet the slopes to resist erosion. The maximum velocities allowable are:—

In light sandy soil ...	1·5 to 2·0 feet per second.
In sandy loam ...	2·5 „ „
In ordinary firm loam ...	3·0 „ „
In stiff clay or *kunkur* soil	4·0 „ „
In shingle and boulders ...	5·0 to 6·0 „ „

[1] See pages 45 and 46.

There are very few main canals in India which run with a higher maximum velocity than 3·0 feet a second: a general maximum is from 2·0 to 2·5 feet.

The dimensions of a main canal are primarily determined by the "duty" of water during a period of pressure, that is, as has been explained in the previous chapter, by the quantity of water which it is necessary to pass on to the land in a short period of maximum demand. Mistakes have not infrequently occurred by working on duties based on the whole irrigating season instead of on this period. It has already been shown how greatly duties vary, and any particular case must be treated accordingly. As a general rule, main canals irrigating *kharcef* (or monsoon) crops should be capable of carrying a maximum discharge of 1 cubic foot per second for every 50 acres of that crop which it is intended to irrigate, and they should be capable of carrying 1 cubic foot for each 100 acres of *rabi* (cold weather) crops. The extent of land which can be irrigated may be determined either by the quantity of water available in the source of supply, or, when that quantity is abundant, by the area which can be commanded by the system. In some cases it is held to be desirable to irrigate only a portion of the area which is commanded, while, in others, no restriction is imposed. Thus, in the Madras works, and in Orissa, water is thrown widely over the largest area possible, but in the United Provinces it is generally considered desirable to restrict the area irrigated to a certain proportion (varying from 40 to 80 per cent.) of the culturable area. In the Bombay Presidency (Deccan) the irrigated area is about one-third only of the area commanded. In the area commanded by the Chenab Canal[1] it has been decided that, as long as the spring level is more than 40 feet below the surface, 50 per cent. of the culturable area may be irrigated; but this limit is to be reduced where the spring level is higher, and irrigation is to be stopped altogether where the subsoil water is within 10 or 15 feet of the surface. In the new project in the Punjab for the irrigation of the Upper Jech Doab and the Upper Rechna Doab the area to be irrigated by both well and canal water is allowed to be 75 per cent. of the culturable area commanded. In the new Lower Bari Doab Canal the irrigation is limited to 50 per cent. of the culturable area in the case of the "bet" lands and 75 per cent. in the "bar" lands. On the Sirhind Canal, only one-fourth or even one-fifth of the culturable areas are allowed to receive water. This restriction is partly due to the desire to spread the available supply of water to as many parts of the district as possible for the benefit of the people, and partly because the light soil of Upper India is liable to become water-logged, and the spring level unduly raised, if irrigation is spread over all the area commanded. This evil is not feared in less permeable soils or where the drainage of the sub-soil is good; in portions of Egypt, for example, the whole face of the culturable land may be said to be covered with water during a part of the year.

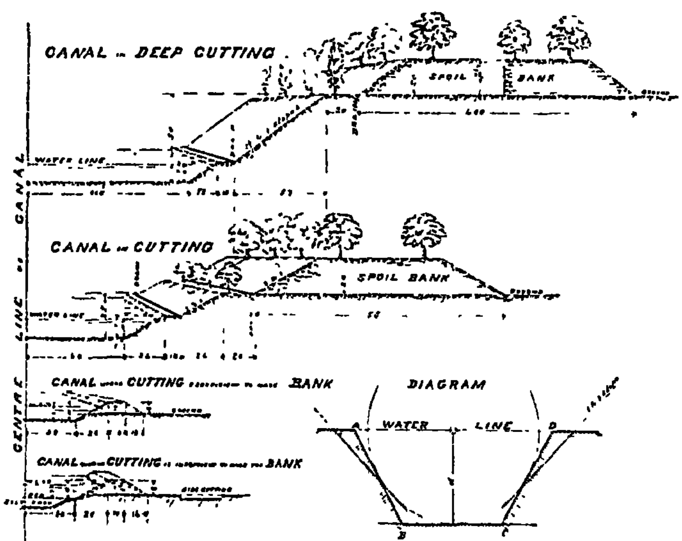
The dimensions of a main canal—indeed, of all channels—are usually determined by the necessities of the *kharcef* or monsoon irrigation, for it is during that crop that the largest quantities of water are, in most cases, required. It is rarely wise, in those cases where the average supply available is greatly in excess of the minimum supply, to base the capacity of a canal on the former quantity, but rather to provide a discharging power only moderately in excess of the minimum. For, although the minimum may occur only at comparatively long intervals, it is at the time, usually, when that minimum does occur that it is most desirable to be able to fully irrigate the area on which cultivation from the canal is practised. If the discharge of the canal, and, consequently, the area dependent on irrigation, is based on the average available supply, it is inevitable that, in a bad year, the canal must fail to fulfil the anticipations of cultivators who have sown crops to the extent which the average supply may justify.

[1] "Recent Developments of Punjab Irrigation," by Mr. Sidney Preston, C.I.E.

When due consideration has been given to these points, and both the maximum discharge and limiting velocity of the main canal are fixed, the proper form and dimensions of the canal can be determined by trial. Kutter's Formula[1] is generally used (with N = 0·025).[2] Trapezoidal sections are always used unless the canal is in rock. The trapezoidal channel which gives the maximum discharge for any given area of waterway, is that of a semi-hexagon (A, B, C, D, in the diagram below), in which—

The hydraulic mean depth = half depth of water.
Depth of water = $0·76 \sqrt{\text{area of waterway}}$ (nearly).
Base of the channel = $0·87 \sqrt{\text{area of waterway}}$ (nearly).
Width at water surface = { twice the width of base or twice the length of one side slope.

But in such a channel the side slopes are only rather more than ½ to 1 (0·58 to 1·0), and it is seldom that so steep a slope can be given in earth cutting. Neville gives the following rule for determining the best form of channel for any given side slope:—



Typical Sections of Indian Canals.

"Describe any circle on the drawing board: draw the diameter and produce it on both sides; draw a tangent to the lower circumference parallel to this diameter, and then draw the side slopes at the given inclinations, touching the circumference on each side and terminating in the parallel lines. The trapezoid thus formed will be the best form of channel, and the width at the surface will be equal to the sum of the two side slopes." This rule is suitable for small channels in which it is possible to make the depth great in proportion to area of the waterway, but it cannot be employed in the case of large canals unless they are drawn from rivers of great depth. For instance, the theoretically perfect channel to carry 2,250 cubic feet of water at a velocity of 2½ feet a second would have:—Waterway, 900 square feet; base (0·87 × 30), 26·1 feet; depth of water (0·76 × 30), 22·8 feet; side slopes, about 0·6 to 1. Such a channel might be suitable for an inundation canal taken from a river—such as the Nile—with a large range of level; but it would be quite unsuitable where the depth of water in the canal is to a great extent determined by the height of the weir crest above the river bed, and by the the practical difficulties and expense of excavation in deep cutting. It frequently occurs that the expense of cutting becomes very great when it has to be carried below spring level. The sections in the above sketch are typical ones of Indian canals.

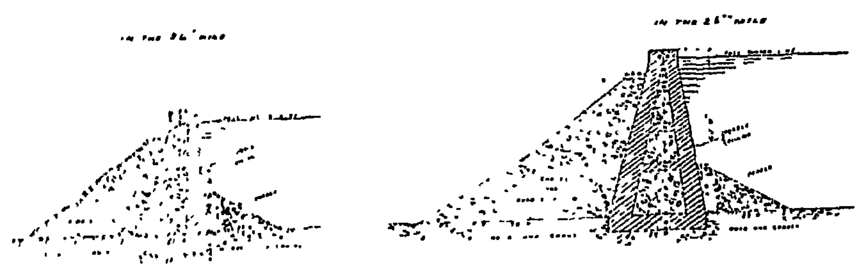
The particular form of cross section suitable to any particular case can only be determined by a system of trial and error, but the calculations are greatly facilitated by the use of one of the hydraulic tables mentioned in the footnote.

[1] Jackson's "Canal and Culvert Tables" or Higham's "Hydraulic Tables" should lie on every irrigation officer's table. Colonel Moore's "New Tables" are more elaborate, but less handy.

[2] The coefficient was taken as N = 0·0225 in the Chenab Canal project.

Where a canal is in deep cutting, as in the two upper sections of the above sketch, it is necessary to make a system of drains on the inner berms, or else the slopes will gutter badly: the drains on the ground level can be either led out through the spoil bank on to the fields or dropped into the canal. In the latter case it is necessary to make paved masonry ducts leading down the slopes into the canal. In the lowest section the case is shown where a canal is in embankment, and the cutting is insufficient to form the bank above ground level. In such cases it is sometimes made up by cutting silt traps below the canal bed, as shown in the sketch. This is a good plan where there is much silt, but, if that is not the case, it is not a good plan, as there would be considerably increased loss of water by absorption, especially in porous soils. Under those circumstances side borrow pits are better.

When a canal is carried on side-long ground, one bank is sufficient to form the canal; many of the canals leading from the larger Bombay tanks are made in this way. Where the slope of the ground is steep, this method is suitable, and, indeed, unavoidable; but where the slope is gentle, the width of the canal at the water-line is necessarily great, and there is much loss of water from absorption and evaporation. Considerable lengths of the Kurnool Canal in the Madras Presidency are made with only one bank, and in parts the side bank is as much as 50 feet in height: there are some miles of banks more than 35 feet in height. In most cases the banks are made of earth only; in others of dry rubble walls with a puddle core between them, faced on the water side with a gravel slope covered with puddle and rubble pitching; in other cases masonry walls, varying from 12 feet to 45 feet in height, were constructed. The sketch shows two examples of masonry walls in lieu of banks as actually constructed on the Kurnool Canal.



MASONRY SIDE WALLS OF THE KURNOOL CANAL, MADRAS.

The statement on the next page shows the cost per mile of some of the chief perennial canals in the Upper Provinces of India; the corresponding figures for the Madras Canals cannot be given, as it is not possible to divide the old outlay upon them between the different portions of the works. The figures show the cost of the main and branch canals only exclusive of head-works, distributaries and drainage works, &c.: they give the actual cost of the canals, and do not include the charges for establishments, tools, &c., for which about 25 per cent. would have to be added.

Branch canals and distributaries may be designed on the same general principle as main canals; that is, that they shall be capable of carrying the discharge which is necessary during the period of maximum demand. In grading the longitudinal sections of distributaries it is desirable to keep the beds of the channels as near as may be at the country level. In Bengal, at any rate, this principle[1] is of importance. The higher lands are usually sandy, and, consequently, have the greater need for irrigation, and are more improved by it than the heavier lands at a lower level. If distributaries are aligned so that the water line is below ground, there is a constant tendency to run water in them at high levels in order to irrigate the higher lands near the distributary which are not, in that case, well commanded. Irrigation controversies in Bengal have established the desirability of refusing irrigation to all

[1] Lecture by C. W. Odling, Esq., C.S.I., delivered at Sibpur Engineering College, February 23rd, 1893.

rice lands which cannot be easily irrigated by flow. Not only are the cultivators of such lands dissatisfied if the irrigation is inefficient, but the constant pressure which is applied to induce the canal officials to raise the level of the water, results, not infrequently, in interferences

COST OF MAIN AND BRANCH CANALS.

Canal	Miles of Main and Branch Canals	Cost Direct Charges.	Average Cost per Mile of Canals	Cost per Irrigable Acre.	Cost for each Cubic Foot of Full Discharge.	Approximate Full Discharge of Canals	Area Irrigable.
	Miles.	Rupees.	Rupees.	Rupees.	Rupees.	Cubic Feet per Second.	Acres.
Burma :—							
Mandalay Canal[1]	39	27,69,467	71,012	31	1,846	1,500	89,000
Swebo Canal[1]	77	21,60,959	28,064	14	831	2,600	150,000
Bengal :—							
Orissa Canals	280	95,51,539	34,112	35	1,592	6,000	275,000
Midnapore Canal	72	35,39,434	49,158	28	2,359	1,500	125,000
Sone Canals	367	103,58,866	28,226	17	1,618	6,400	600,000
Dhaka Canal[1]	18	1,07,292	5,960	8	357	300	13,500
Trebeni Canal[1]	60	22,81,321	38,022	20	1,140	2,000	114,000
United Provinces :—							
Ganges Canal	440	1,70,07,542	38,653	13	2,126	8,000	1,300,000
Lower Ganges Canal	768	1,91,93,463	24,991	15	3,838	5,000	1,244,000
Agra Canal	109	45,21,848	41,485	14	2,260	2,000	312,000
Eastern Jumna Canal	129	figures doubtful.	—	—	—	1,800	337,000
Betwa Canal	168	17,07,979	10,166	16	1,708	1,000	106,000
Punjab :—							
Western Jumna Canal	347	68,33,539	19,693	8	1,068	6,400	809,000
Bari Doab Canal	369	1,00,55,729	27,251	12	1,547	6,500	849,000
Sirhind Canal	538	1,84,30,694	34,258	16	2,248	8,200	1,170,000
Chenab Canal	426	1,22,31,577	28,712	8	1,133	10,800	1,600,000
Jhelum Canal	113	42,17,171	37,320	16	1,110	3,800	266,500
Sidhnai Canal	68	4,58,208	6,738	2	191	2,400	195,000
Madras :—							
Penner River Canals	31	13,19,235	42,556	9	188	7,000	145,500
Srivaikuntam System	28	5,73,983	20,499	21	239	2,400	27,800
Barur Tank	7	1,21,386	17,341	21	—	—	5,800
Periyar Reservoir System	36	13,85,552	38,487	12	—	—	110,900
Rushikulya System	80	16,37,537	20,469	16	—	—	102,000
Bombay :—							
Nira Canal	100	18,93,368	18,933	17	—	—	113,300
Mhasvad Tank	66	5,60,415	8,491	23	—	—	24,800
Kadva River Works	25	90,140	3,605	6	—	—	14,600
Mutha Canal	88	18,19,881	20,680	108	—	—	16,800
Sind :—							
Jamrao Canal	180	37,45,788	20,809	15	1,170	3,200	254,100
Desert Canal	253	17,97,261	7,104	14	486	3,700	130,000
Unharwah	98	4,35,391	4,442	8	189	2,300	56,000

with the flow of the water in the distributary, which are injurious to the irrigation of lands lower down the channel. If the original grading a distributary has placed the water-line too low, demands arise for the construction of regulators to raise the level of it. Except in rare cases, regulators in distributaries should not be allowed: at the best they are evils

[1] Incomplete: Estimates taken.

which lead to difficulties with silt deposits in some cases, and, in nearly all cases, they are a source of friction and dispute with the people.

Some branch canals, and all distributaries, are subject (or should be subject) to the system of rotation or *tatils*, which has been described in the last chapter; and this is a factor which has to be taken into consideration in settling the capacity of a distributary, as a larger channel is, of course, necessary when *tatils* are enforced than when a system of constant flow is permitted. If the system of *tatils* and the duty of water in the distributary are both known, the capacity of the channel is easily determined. Thus, taking the cases of distributaries V and Z in the sketch on page 285, distributary V irrigates 4,750 acres, and distributary Z 5,700 acres of khareef crop, and the duty of water at the head of each is considered to be 75 acres to a base of 15 days. V is open for 10 days in 14, and Z for 12 days in 14, as shown in Tatil Table No. 1, but a period of 15 days may be selected in each case during which V is only open for 10 and Z for 12 days. In order to gauge the required discharge of the distributaries, the duty of each must be reduced to the base of 10 and 12 days respectively. A duty of 75 acres to a base of 15 days is equivalent to 5 acres to a base of 1 day or 50 acres to a base of 10 days, and 60 acres to a base of 12 days. The required discharges are therefore—

In the case of distributary $V = \frac{4{,}750 \text{ acres}}{50} = 95$ cubic feet a second.

" " " $Z = \frac{5{,}700}{60} = 95$ cubic feet a second also.

The latter distributary requires the same discharge for 5,700 acres as the former does for 4,750, simply because it runs for a longer period.

The duty of 75 acres to a base of 15 days is equivalent ($S = \frac{B}{D} \times 23{\cdot}8$, page 271) to a depth of 4·8 inches in the field, if the whole discharge reaches it, or to about 4 inches if only 10 per cent. of the discharge of the distributary is lost by absorption, &c., on its way to the field. In cases where only one crop is grown—say rice—and when the depth of the watering required in a given time during a period of pressure is known, it is easier, perhaps, to work on the basis of the volume required in the time for the area to be irrigated. Thus: a distributary has to irrigate 5,000 acres of rice crop, and it is considered necessary at the time of maximum demand to place 4 inches of water in all the fields during a period of 12 days; then (by Formula III., page 271) the required discharge is $= \frac{A\ S}{B \times 23{\cdot}8} = \frac{5{,}000 \times 4}{12 \times 23{\cdot}8} = 70$ cubic feet, which must be increased by the estimated loss in the village channels and in the distributary, an amount which may vary from 10 per cent. to 50 per cent., according to the length of channel, nature of soil, &c.

The dimensions given to distributaries in Upper India are usually determined as follows:—

T = gross area of tract commanded by a distributary.
t = area of unculturable land, *i.e.*, roads, village sites, waste land, &c.
b = proportion of the culturable land which is to be irrigated during the year (varies from 1·0 to 0·20).
k = proportion of area to be irrigated which is cultivated in khareef crops.

Then $T - t$ = culturable area commanded by the distributary:

and $T - t \times b \times k$ = area of khareef crop to be irrigated.
= A of Formula III., page 271.

So that the discharge of the distributary (x) has to be

$$x = \frac{A}{D} = \frac{(T - t)\,b\,k}{D}.$$

The values given to b and k vary according to the conditions of cultivation in different localities. In one case in the Punjab, b is taken as 0·25 and k as 0·4. That is, only one-quarter of the culturable area commanded by a distributary is allowed to be irrigated in the year, and two-fifths of this area is considered to be khareef crops. D is taken as 60, so that—

$$x = \left.\begin{array}{c}\text{discharge of any distributary}\\ \text{in continuous flow}\end{array}\right\} = \frac{(T - t) \times 0{\cdot}25 \times 0{\cdot}40}{60}$$

$$= \frac{T - t}{600},$$

and the capacity of the distributary has to be increased beyond this in proportion to the *tatils* which are to be enforced. In another case in the Punjab, the discharge of a distributary (for continuous flow) is taken as $\frac{T}{760}$: which is equivalent to $\frac{T - t}{570}$ (if t is taken at 0·25 of T, as is often the case). On the Ganges Canal in the United Provinces a further factor—

c = area already irrigated by wells in the tract commanded by a distributary—

is taken into consideration: the value of b is taken as 0·8 and k as 0·5 and:—

$$\text{The area of } \textit{khareef} \text{ crop to be irrigated is } = (T - t)\,k\,b - c$$
$$= (T - t) \times 0{\cdot}4 - c.$$

A duty of 70 acres was taken in most cases, so that:—

$$x = \left.\begin{array}{c}\text{discharge of any distributary (for}\\ \text{continuous flow)} \;\; ..\end{array}\right\} = \frac{(T - t) \times 0{\cdot}4 - c}{70}$$

and where c was $= 0$ the discharge of a distributary became $\frac{T - t}{175}$.

In the Sone Canals in Bengal, b has usually been taken as 1·0 and k as 0·5, and a duty of 80 acres for the season was assumed, so that—

$$\text{The discharge of a distributary (for continuous flow) became} = \frac{(T - t) \times 0{\cdot}5}{80}$$

$$= \frac{T - t}{160};$$

but of late years the duty has been taken at a lower figure for the reasons explained in Chapter XV., and some distributaries have been constructed on the basis of a duty of 50 acres, which is a much more correct figure in this case. In all these examples the base of the duty has not been expressed, and the formulæ rather produce the impression that it is necessary to have 1 cubic foot of water running in a distributary for the whole season to mature 60, 70, or 80 acres, as the case may be, of *kharref* crops. This is not the case, and the duties really are applicable to the periods of pressure, or, say, to bases of about 15 days. In these examples, too, the result is in all cases for continuous flow, and where tatils are enforced, the capacity of the distributary is increased in proportion to the closure which is contemplated. In Bengal (on the Sone Canals), closures of entire distributaries for half-time were provided for, and the channels were cut to carry twice the discharge given above. This period of closure is excessive: five days' closure in fifteen is sufficient. In the Sirhind Canal distributaries, no closures are provided for, and tatils are enforced on the minor channels only.

A distributary which is designed for the *khareef* demand is always more than large enough for the rabi crops, for the areas of the two crops are generally taken in Upper India as about the same, and the duty of water in the cold season in any distributary is generally at least double the duty in the *khareef* season.

This variation in the discharge of a distributary introduces some difficulties in the grading and section of the channel: it is generally better to grade the channel mainly with reference to the rabi discharge, so that the surface of the water when running in low supply may be, on the average, about 1 foot above ground level. Distributary slopes are usually cut at 1 to 1, but where there is silt in the water the sides generally silt up to slopes of about ½ or ⅔ to 1, so that it is best to base all calculations of discharge on those reduced slopes. These silt berms are a great protection against percolation and absorption, and they should never be cut away unless the discharge of a distributary is injuriously affected by them.

The efficiency of a canal depends largely on the degree of perfection of its distributary system. It was originally the practice in India[1] for the Government to construct the main canals and branches and to leave the construction of distributaries and subsidiary channels in the hands of the people. It was soon found that this system was a bad one, and Government undertook the construction of nearly all channels, leading direct from the main canals, of a capacity exceeding 15 or 20 cubic feet per second. From these distributaries, or *rajbuhas* as they are called in Upper India, the village channels were supplied. These were, usually, made by the villagers. On the Sirhind Canal, in the early 'eighties, the principle was adopted that Government should construct the channels necessary to convey the water to the boundary of every village which it was intended to irrigate. On the more recently constructed canals the canal officers undertake the alignment, grading, and even the construction, of all village water-courses, the actual cost only being recovered from the villagers. On the Chenab Canal the levels of the area commanded have been determined at intervals of 550 feet, and a large scale contour map has been prepared of the whole area. On these maps the engineers lay down the traces of the major and minor distributaries; the holdings are divided into groups, and each group has a watercourse assigned to it. It is a cardinal principle that no watercourse is carried across a drainage. A certain width along all well-defined drainages is reserved as common land, so that there may be no obstruction to the escape of the drainage by cultivation. These measures, while they involve a heavy outlay by Government, really repay that outlay by the greater efficiency of the irrigation, and, consequently, the more rapid development of it.

The more perfect the village channels are the greater duty can be obtained from the water, but it is often a matter of great difficulty to induce the villagers to make them properly; or, if they do make them well, to maintain them in a proper condition. This is more especially the case where large tracts of rice land are irrigated, for it is so easy to pass the water from field to field when every field is more or less submerged, and this method is so widely practised by the cultivators when they mature the rice crops by the rainfall only, that it is difficult to get the villagers to see any advantage in the village channels: indeed, in many cases there is no advantage when there is an unlimited supply of water; but, when the supply is limited, there is no question that a larger area can be efficiently irrigated, with the same supply, if proper channels are made. In some rice tracts—such as those irrigated by the Midnapore Canal in Bengal—floods occasionally occur which are very destructive to small channels; so much so, that in more than one case, they have completely disappeared in a few years. In Madras, where rice is mainly cultivated, village channels are rarely made, and the irrigation is effected by a system of wide-spread flow from field to field. In Orissa and Midnapore also, where rice is the

[1] Note by Sir Thomas Higham, K.C.I.E., St. Louis Exhibition, 1904.

main crop, it has been found impracticable to enforce the construction of village channels from the distributaries, and the system of widespread field to field irrigation is acknowledged. Under this system villages which are near the distributaries are well protected, but, in a time of pressure, those which are far from distributaries, and can only obtain water through intervening villages, are in a very unfavourable position. The practice of this method of irrigation has made it necessary to introduce a complicated system of supplying water, under which a distant village is refused a supply unless either the intervening villages are leased for irrigation or the distant village will construct the necessary channel.

The following statement shows the cost of distributaries, per mile and per acre irrigable, on some of the chief perennial systems of Upper India. The figures are the actual cost of the works, including land, but they do not include the charges for establishment, tools, &c., for which an addtion of about 25 per cent. must be made:—

COST OF DISTRIBUTARIES.

Canal	Miles of Distributaries.	Cost Direct Charges	Average Cost per Mile	Average Cost per Acre Irrigable.
	Miles.	Rupees	Rupees	Rupees.
Bengal:—				
Orissa Canals	1,145	25,23,250	2,204	9·1
Midnapore Canal	314	8,95,484	2,852	7·2
Sone Canals...	1,217	46,03,306	3,782	7·7
United Provinces:—				
Ganges Canal	2,709	52,75,154	1,947	4·0
Lower Ganges Canal	3,243	49,00,321	1,511	3·9
Agra Canal	610	12,85,160	2,107	4·1
Eastern Jumna Canal	679	3,68,504	543	1·1
Betwa Canal	388	4,64,854	1,198	4·4
Punjab:—				
Western Jumna Canal	1,803	37,49,410	2,079	4·6
Bari Doab Canal	1,579	38,49,759	2,438	4·5
Sirhind Canal	4,639	56,13,889	1,210	4·8
Chenab Canal	2,224	48,30,567	2,172	3·0
Jhelum Canal	321	16,22,885	5,056	6·0
Sidhnai Canal	131	2,14,276	1,636	1·1
Madras:—				
Penner River Canals	416	11,36,510	2,732	8·0
Srivaikuntam Anicut System ...	62	2,34,361	3,780	8·0
Barur Tank	22	89,484	4,067	15·4
Periyar System	186	8,74,253	4,700	8·0
Rushikulya System...	137	4,76,194	3,476	4·6
Bombay:—				
Nira Canal	139	2,05,139	1,476	1·8
Mhasvad Tank	34	84,705	2,491	3·4
Kadva River Works	14	22,891	1,635	1·6
Mutha Canal	67	8,15,387	12,170	48·5
Sind:—				
Jamrao Canal	391	14,24,260	3,643	5·6

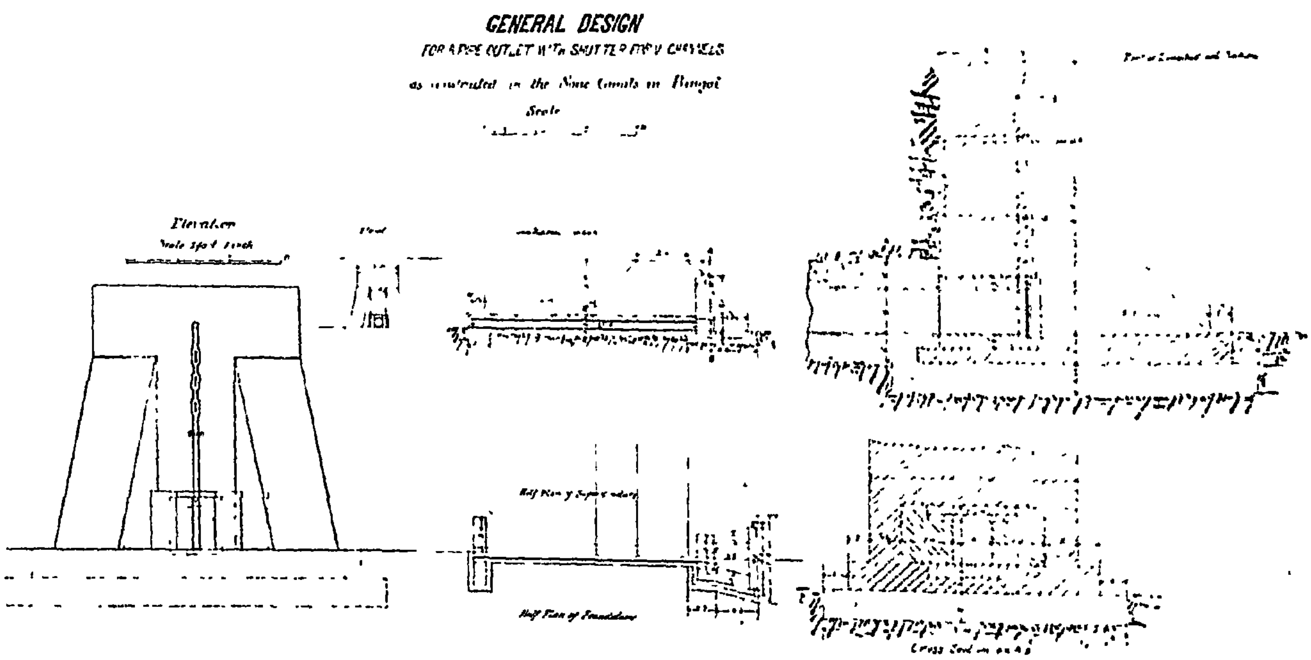
The cost of distributaries in the Punjab per acre of gross area *commanded* (of which, roughly, one-half may be actually irrigated) are approximately as follows in four of the large systems:—

COST OF DISTRIBUTARIES

Class of Work	Estimates.			Actual.
	Upper Jhelum.	Upper Chenab	Lower Bari Doab	Lower Chenab.
	Rupees.	Rupees.	Rupees.	Rupees.
Preliminary and Land	0·43	0·65	0·22 [1]	0·04 [1]
Earthwork	0·51	0·44	0·55	0·40
Masonry Works	1·51	1·28	1·23	0·92
Outlets	0·08	0·07	0·06	0·08
Contingencies	0·17	0·16	0·14	0·16
Total	2·70	2·60	2·20	1·60

The major distributaries in the Upper Jhelum, Chenab, and Lower Bari Doab Canals are estimated to cost Rs. 4,000 to Rs. 5,000 per mile, and the smaller distributaries Rs. 2,400 to Rs. 3,100 per mile.

The small heads by which water is drawn from a distributary into a village channel are



PIPE OUTLETS FOR VILLAGE CHANNELS IN BENGAL.

called outlets. The Plate on page 296 and the sketch above show various forms of these which are in use. In some few cases, where large areas are irrigated from the same outlet, masonry vents are constructed, but as a rule outlets in distributaries and "minors" are made

[1] Cost of land nominal in these two cases, being mostly Crown land.

with circular pipes: these vary in size from 3 inches to as much as 12 inches, but in a majority of cases 6-inch pipes are found most convenient, and if one of these is not sufficient two or more are fixed. The outlets in many cases are closed by a clod or piece of turf only, or by a wooden plug, but where *tatils* have to be enforced, with perhaps some difficulty, locked valves or shutters of some kind have to be fitted. Some of these are shown on the Plate.

Economy of water results from a careful restriction of the size of the outlet to the area under irrigation from it. It has already been mentioned that there is probably more loss of water in village channels than in other parts of an irrigation system; this loss is enormously increased when extravagant outlets are provided. This is more particularly the case in rice irrigation, where the cultivators have generally many opportunities of passing off superfluous water unnoticed; if the outlets are larger than is really necessary, a cultivator will often allow water to run through his fields for no good purpose, but if his outlet is proportionate to his real needs he is more careful of the supply, and will thus leave more water available for his neighbours. A good general rule for the size of outlets is that in the *khareef* season they should be capable of delivering 4 inches of water in depth over the area irrigable in a period of ten days, and in the *rabi* season they should be capable of giving a depth of 2½ inches in fifteen days. The discharge of an outlet varies, of course, with the head upon it, and the head varies with the supply in the distributary. In the Sone Canals in Bengal, where large tracts of rice have to be irrigated, observations are recorded, at times of pressure, of the actual difference in level between the water in the distributary and in the channel below the outlet, with the object of recording facts to aid in the proper calculations of the outlets, but in most cases it is usual to assume a moderate head of about 6 inches in the *rabi* season, and to base the size of the outlets on the hypothesis that the head is constant. A rule has been in force on the Ganges Canal that each square inch of ventage is sufficient for 1¼ acres of *rabi* when *tatils* of half time are allowed. It will be found that this rule agrees fairly well with the general one which has been given above. The discharge from pipe outlets is usually calculated from the formula used for orifices, which is sufficiently accurate for practical purposes, but experiments have shown that it is well to give a value of 0·6, or even 0·5, to the coefficient c in the formula, as the pipes are rough, and often not very truly laid.

It is generally agreed that it is best, as a rule, to place the outlets in distributary banks at the level of the bed of the channel, except in the upper reaches of large distributaries, where a sufficient head of water can be relied upon, and that the upper edge of the vent should, even in such cases, be 2 feet below the full supply level. The rule which is sometimes used of placing the outlet at a fixed depth below the full supply level, often results in inconvenience when some particular crop—sugar-cane, for instance—requires a very small supply of water when the distributary is low. The objection to placing outlets at the bed level is the difficulty which arises in closing them in more than 2½ feet of water, unless they have sliding shutters.

In connection with every irrigation system it is necessary to construct a series of drains to carry off the surplus water after it has completed the irrigation of the crops. If this important element in an irrigation scheme is neglected, the land may become waterlogged and sterile. The extent to which it is necessary to construct drainage channels varies greatly with the nature of the soil, with the proportion of *khareef* crops, and with the levels of the country. In many tracts the natural drainages are clearly marked, and lie sufficiently below the irrigated fields to effect the purpose without artificial means, especially if the subsoil is sandy. In other parts, where the natural drainages are ill-defined, and very probably cultivated, it is necessary, especially if the soil be stiff, to acquire a strip of land in the low ground lying between two irrigation channels, and construct a drain to carry off surplus water to the nearest stream.

The Plates on pages 14 and 16, show some of these drains in the Madras Delta Systems. In India such works, where they have to be constructed, must, in most cases, be designed to carry off a portion of the rainfall in addition to the surplus water from irrigation, and they vary in capacity from 2 up to 50 or even 80 cubic feet per second per square mile, of which only a very small portion is water from the canals. In Egypt, where there is practically no rainfall, it is usually considered that provision should be made for draining off 8 cubic metres (283 cubic feet) per day from each acre, which is only about 2 cubic feet per second per square mile. Drainage works are usually carried out gradually as irrigation develops, and as the necessity for them in certain parts becomes manifest. One of the most elaborate systems of drainage, which has been gradually developed, is that of the Ganges Canal system. There are no less than 1,730 miles of drainage channels as compared with 3,243 miles of irrigation channels of various kinds.[1] The result of these works has been that lands which previously remained flooded until late in the cold-weather season are now drained in time for the *rabi* sowings; the rise in the level of the subsoil water has been checked, and the sanitary condition of a large number of towns and villages has been greatly improved.

COST OF DRAINAGE AND PROTECTIVE WORKS.

Canals	Cost of Works	Cost per Acre Irrigable
	Rupees	Rupees
Bengal :—		
Orissa Canals[2]	21,52,804	7·9
Midnapore Canal	3,56,190	2·8
Sone Canals	8,70,070	1·4
United Provinces :—		
Ganges Canal	15,52,269	1·2
Lower Ganges Canal	4,68,496	0·3
Agra Canal	2,64,287	0·8
Eastern Jumna Canal	6,84,056	2·0
Betwa Canal	*Nil.*	—
Punjab :—		
Western Jumna Canal	7,41,357	0·9
Bari Doab Canal	1,22,989	0·1
Sirhind Canal	10,65,288	1·0
Chenab Canal	1,56,025	0·1
Jhelum Canal	13,177	—
Sidhnai Canal	36	—
Madras[3] :—		
Penner River Canals	3,18,258	2·2
Srivaikuntam Anicut System	35,256	1·2
Barur Tank	*Nil.*	—
Periyar Reservoir System	9,741	—
Rushikulya System	4,144	—
Bombay :—		
There are very few drainage and protective works in Bombay. The irrigation systems are generally on land, with a marked slope, which has natural drains.		

[1] Note by Mr. Hutton, Superintending Engineer.

[2] There is an extensive system of embankments on these canals.

[3] Correct figures for the larger Madras Works are not obtainable.

The foregoing statement shows the cost of drainage works in some of the principal perennial canals of Upper India. The reason of the high cost of the works in Orissa is mainly because the figures include the cost of heavy protective embankments in the Delta,[1] which exclude floods from the irrigated tracts. In the other cases the figures are almost exclusively for drainage works alone. The figures give the actual cost of the works, including land, but exclusive of charges for establishment, &c., for which about 25 per cent. has to be added.

[1] See page 100.

CHAPTER XVII.

REVENUE AND ADMINISTRATION.

Irrigation Revenue—Miscellaneous Revenue—Consolidated Rate—Occupier's Rate—Owner's Rate—Enhancement of Land Revenue due to Canals—Administration—Assessment of Irrigation Revenue—Cost of Revenue Management—Cost of Working Expenses.

THE revenue which is earned by the irrigation works of India comprises, first, that which is derived from the use of the water for the crops; this is called "Irrigation Revenue" proper—and it amounts to about 94 per cent. of the total; and, secondly, the revenue which is derived from the many subsidiary services, rendered by an irrigation system, which are not immediately connected with the watering of crops, such as the tolls received from navigation, the proceeds from plantations, water-power, fisheries and other miscellaneous items.

The returns from navigation are considerable in Bengal and Madras, but in the other provinces they are insignificant. Sale of water-power brings in nearly two lakhs of rupees a year in the Punjab and about half that sum in the United Provinces; in these provinces small mills for grinding corn are erected at many of the canal falls. The revenue from plantations is best in the United Provinces, where there are extensive areas, on the banks and on the surplus lands connected with the canals, which are excellently planted with revenue-producing trees.

The "Irrigation Revenue" proper, which is derived entirely from the watering of crops, is assessed in ways which vary according to conditions of cultivation, and according to the method of assessment of the Land Revenue in the different provinces. The Land Revenue forms the greater portion of the public revenues of India. It is a tax or rent charged by Government on all occupied lands, and is collected in some provinces directly from the *ryots* or occupiers of the fields, and in others from the *zemindars* or landowners, who collect their own rents from the *ryots*. The Irrigation Revenue, which is derived from the watering of lands, does not depend on the volume of water supplied, which may vary greatly according to climate, soil and rainfall, but primarily on the nature of the crop and on the areas actually or ordinarily irrigated. It may be said that the charge is made for ensuring the maturity of the crop, and that sufficient water is guaranteed to effect that purpose. Under the old native Governments the Land Revenue, which formed then, as now, the greater portion of the State revenues of India, used to be largely collected in kind, and under that system the State's share of the produce increased with the introduction of irrigation. When, under British rule, cash payments were introduced in place of payments in kind, the assessments of the Land Revenue were made on the basis of the average produce. Lands which were assured of irrigation were, consequently, assessed at higher rates than others which had not that advantage. The difference between the two rates represented the true revenue earned by the irrigation works. In cases where the lands were annually under irrigation it was possible to institute a "consolidated" rate, which included both the Land Revenue due to the State for the land itself—which would be that of similar unirrigated lands in the same district—and the rate due for the advantage given by the irrigation works. This system of a "consolidated" rate is followed throughout the Madras Presidency, in Sind, on a number of old irrigation works in Bombay, and in the Burma districts which have

undergone settlement. In Sind, indeed, where crops are grown only on irrigated land, and where land without water is valueless, it is almost impossible to say what portion of the gross revenue is due to the land and what portion to the irrigation works. The practice there is to assume an arbitrary proportion—usually 90 per cent.—as being the revenue due to the works.

In the four provinces of Upper India, and in parts of Bombay, the Irrigation Revenue is not assessed with the Land Revenue, but is distinct from it, and, although it is usually collected by the same establishment, it is, in nearly all cases, assessed by the Irrigation Officers, and not by the Civil Department which makes the assessments and collections of the Land Revenue. In these provinces Irrigation Revenue consists of (1) Occupier's rate, (2) Owner's rate, and (3) Enhancement of land revenue due to the canals. The Occupier's rate (1) is the water-rate payable by the *ryot*, the tenant and actual cultivator of the soil; it is assessed on the area irrigated, and varies according to the nature of the crop irrigated.

The Owner's rate (2) and the Enhancement of Land Revenue (3) are, essentially, the same thing. They are the share due from the *zemindar* or landowner on account of the enhanced value of his property due to the irrigation works. The rate is called an Owner's rate when it is assessed on the owner separately from the land tax, but, when this tax is revised, from time to time, at the settlement periods, the Owner's rate may be amalgamated with the land tax, and then the share due to the irrigation works is credited to them as "Enhancement of Land Revenue."

It might be thought that if the *ryot* or occupier was charged a sufficiently high rate for irrigation, that it would be simpler to collect the entire Irrigation Revenue from him,[1] but, owing to a variety of causes, it is, in almost every case, impossible, with due regard to extension of canal irrigation, to charge so high a rate for the water to the cultivator as to preclude the *zemindar* (or landowner) from reaping some advantage from the introduction of canal irrigation by a rise in the rent, which he collects from the cultivator, for the canal irrigated land. Nor, indeed, is it desirable that this should be done. In order, for instance, to do this effectually, it would be necessary to drive a separate bargain with each cultivator for each crop grown under canal irrigation, which would be practically impossible. In order to secure rapid and economical assessment of the canal revenue, canal rates must be uniform for each class of crop, and cannot take into consideration differences in the quality of the crops watered, differences arising from the varying nature of the soil, style of cultivation, and other causes independent of the canal. But all-round crop and acreage rates, applicable to wide areas and to various soils and classes of cultivators, must be kept at a comparatively low average, in order to avoid undue pressure on the poorer soils and unfavourably situated localities. Therefore rents invariably rise more or less after the introduction of canal irrigation, and the Government steps in, by means of the Owner's rate, to claim its share in the profits which are being reaped by the landlord from the operation of works constructed by the State.

The Land Revenue is adjusted from time to time by a revised settlement of the land tax, a rent which is paid to Government. This is the case in all provinces except Bengal, in which the land tax was crystallised for ever by the famous "Permanent Settlement" of Lord Cornwallis. Owner's rate is theoretically a special rate imposed, during the currency of a settlement, on landlords, in order to secure the Government share of the increase in rental due to canal irrigation, and is limited, in most cases, to half the difference between the rent paid before and that paid after the introduction of this irrigation. On the expiry of a settlement and introduction of a new one, the Owner's rate, or a certain portion of it, may either be

1 "Note on the Basis on which Irrigation Revenue is Calculated," by Colonel H. A. Brownlow, R.E., formerly Inspector-General of Irrigation in India, Feb. 14th, 1884.

amalgamated with the Occupier's rate, or, if the latter be maintained constant, the whole of the Owner's rate may be merged in the Land Revenue, and appear as an indirect credit to the Irrigation Works as "Enhancement of Land Revenue due to Canals."

One of the reasons for the unfavourable financial results displayed by the canals in Bengal[1] is that up to the present time no Owner's rate has been assessed and no Enhancement of Land Revenue has been made. Unfortunately the areas watered by the Sone and Midnapore Canals lie within the tract where the Permanent Settlement has finally fixed the Government Land Tax, and it is impossible for Government to obtain the revenues from the Irrigation Works which are really their due.

In Bengal it has been found convenient to grant leases for long terms of years, and almost the whole of the water available on Bengal Canals has been hypothecated by such leases. The system, which is known as the "block" system, has been proposed also for introduction in parts of Bombay. Under this system the cultivators in any suitable "block" of land enter into a joint lease, usually for seven years, and they pay annually for the water whether they actually take it or not. The rate paid is subject to periodical revision when the leases fall in, and the rates are being gradually enhanced. Remissions are freely given in the case of failure of crops, even where the failure is in no way due to deficient supply. It has been found, however, that in spite of these facts, and in spite of the Bengal Tenancy Act, the landlords have succeeded in enhancing the rents, noticeably in the Sone Canals, to a large extent. This increment, which is largely due to the canals, is entirely absorbed by the landlords, and Government obtains no share of it, as they do in other provinces in the shape of Owner's rate or Enhanced Land Revenue.

The assessment of Irrigation Revenue is made, in Upper India, under the direction and control of the officers of the Irrigation Branch of the Public Works Department; these are the same officers—Engineers—who maintain the works in an efficient state, and control the distribution of the water to the fields. A Chief Engineer, who is usually also Secretary to the Local Government in the Public Works Department, is at the head of the establishment of the province; under him are Superintending Engineers of "circles," who have jurisdiction over areas which may include from half a million to a million acres of irrigation: next come the Executive Engineers, who control "divisions," which vary in size up to areas which may include as much as 200,000 acres of irrigation. The Executive Engineer is the officer who is responsible for the proper assessment of the Irrigation Revenue, and generally for the collection of the other revenue earned by the canals: he is also responsible for the repairs of the works, for the preparation of projects for the improvement of his division, and for the proper regulation and distribution of the canal water. He is assisted by a large establishment of Government officials, chiefly composed of natives of India, who live in the various "sub-divisions" and "sections" into which the division is divided.

The establishment of the Public Works Department is divided in some provinces into two distinct branches, one of which deals almost exclusively with the Irrigation Works, and the other with the other public works of the province. But in some cases the irrigation officers undertake the charge of all the public works, except the railways, which lie in the districts under their charge, so their duties are often very multifarious.

The system of assessment of the Irrigation Revenue varies on different canals, but substantially the assessment is made in the following manner by the officials named:—

The Patrol, who is an intelligent peasant, capable of reading, writing, and making rough measurements, visits and inspects the irrigation in his beat at frequent intervals, and records in

[1] See Chapter XVIII., pages 311 and 313.

his register (*shudkhar*) each field as it is irrigated, with certain statistics concerning it. His register is the primary record of irrigation. With the help of this register:—

The Ameen, who is a superior man who can survey and measure land accurately, prepares a measurement register (*khusrah*) of the areas irrigated. This document may be the result either of actual measurement with a chain, or it may be prepared from the village maps, which, where they are available, give the area of each field and other statistics. The Ameen's measurement-sheet is usually attested by the signature of the head-man of the village, by the village accountant (the *putwarce*), and often by other persons who are interested, in token of its correctness. From this document the demand statement (*khationcc*) is prepared, either at the time of the measurement by the Ameen himself, or subsequently in his office, with the help of a number of native writers (*mohurirs*). The work done by the Ameen is subjected to scrutiny by:—

The Zilladar, who is a step higher in official rank than the Ameen, and who understands the law and procedure better. This official makes measurements to check the work of the Ameens, and generally supervises the assessments. He hears and decides questions which are preferred by the cultivators regarding their irrigation and assessment. In some cases there is another official:—

The Deputy Collector, who is a subordinate judicial official of some standing in the Civil Department, is appointed to supervise the work of a number of zilladars, and to hear suits in court which may arise in connection with irrigation. But he rarely interferes with the assessment papers.

The Sub-divisional Officer, who is generally an Assistant Engineer, but in some cases a Subordinate in the Public Works establishment, has the general supervision of all these lower officials. He is a gazetted officer, on whom the real responsibility of the assessments rests. He hears complaints and practically decides most cases in which claims are made for remissions. He is almost incessantly travelling about over the irrigated fields, listening to the complaints and wishes of the cultivators. He countersigns the demand statements (*khationces*) after they have been worked out by his subordinates, and forwards them to the Executive Engineer.

When the demand statement has been finally approved, it is sent by the Executive Engineer to the Collector of the district, and the money which is due is recovered by that officer with the Land Revenue. But in Bengal the collectors are made for a special staff working under the orders of the Superintending Engineer. There is always the right of appeal to the Collector of the district.

The Patrol wears a uniform, and is an important person among the cultivators who irrigate from the canals. He has many duties to perform, in connection with the irrigation, which vary in different canals; in some cases he sees to the distribution of the water, while in others he only concerns himself with the record of areas irrigated. His pay varies from 5 to 10 rupees a month, and he deals with 1,500 to 3,000 acres of irrigation. The Ameen draws from 10 to 25 rupees a month, and will generally deal with 7,000 to 10,000 acres of irrigation. The Zilladar draws from 50 to 100 rupees, and will supervise 30,000 to 50,000 acres. The Deputy-Collector will probably deal with 80,000 to 120,000 acres, and his pay will be from 200 to 300 rupees.

It may seem that the establishment which is employed is a formidable hierarchy. The tendency in India, there is no doubt, is to multiply officials and divide responsibility to too great an extent, but the work of the assessment of irrigation revenue is extremely laborious, and the documents are very bulky, in consequence, chiefly, of the small area of land held by each cultivator. In Orissa, for instance, which is, however, rather an extreme case, the average demand from each cultivator is less than one rupee and a half. The labour and difficulty, both

of assessment and collection, may be imagined when such petty sums have to be collected from some 200,000 men distributed over a large tract of country.

IRRIGATION REVENUE, REVENUE MANAGEMENT AND WORKING EXPENSES IN 1902—1903.

System	Incidence of Irrigation Revenue per Acre Irrigated.	Cost of Revenue Management. For Each Rupee of Irrigation Revenue.	Cost of Revenue Management. For Each Acre of Land Irrigated.	Maintenance of Works per Acre Irrigated.	Total Working Expenses per Acre Irrigated, including Revenue Management, Maintenance Charges, and Indirect Charges.	Percentage of Working Expenses on Gross Receipts.
	Rupees	Rupees.	Rupees	Rupees.	Rupees.	
Bengal:						
Orissa Canals	1·32	0·48	0·64	0·95	1·73	96·37
Sone Canals	2·85	0·18	0·53	0·54	1·18	39·54
United Provinces:—						
Ganges Canal	4·88	0·09	0·46	0·82	1·37	27·24
Lower Ganges Canal ...	3·06	0·13	0·41	0·93	1·43	45·05
Agra Canal	3·55	0·11	0·40	0·66	1·14	30·57
Eastern Jumna Canal . .	5·47	0·05	0·26	1·54	1·90	33·55
Punjab:—						
Western Jumna Canal ..	2·78	0·22	0·61	0·85	1·57	36·77
Bari Doab Canal	3·73	0·09	0·35	0·70	1·11	28·29
Sirhind Canal . ..	3·48	0·13	0·44	0·64	1·16	31·92
Chenab Canal . .	3·90	0·09	0·33	0·38	0·77	19·39
Sidhnai Canal	3·10	0·19	0·61	1·59	2·32	73·41
Jhelum Canal	2·12	1·07	0·23	0·79	1·08	396·29[1]
N. W. Frontier Province:—						
Swat River Canal	2·97	0·11	0·34	0·12	0·51	16·77
Madras:—						
Godavery System .. .	4·82	0·11	0·52	0·59	1·18	23·72
Kistna System	5·16	0·11	0·56	0·59	1·20	22·72
Cauvery System .. .	4·77	0·10	0·49	?	0·48	10·19
Penner River System .	6·09	0·10	0·63	0·53	1·23	19·93
Periyar System	10·65	0·11	1·11	2·19	3·42	32·01
Sind:—						
Desert Canal	1·08	0·05	0·06	0·51	0·58	53·50
Unharwah Canal . .	1·75	0·06	0·10	0·46	0·57	32·74
Begari Canal	1·83	0·06	0·11	0·41	0·53	28·80
Eastern Nara Canal ..	2·07	0·06	0·14	0·31	0·47	21·66
Jamrao Canal ...	2·05	0·07	0·15	0·71	0·90	43·52
Average of all Major Works ...	3·18	0·11	0·36	0·63	1·19	31·83
Average of all Minor Works ..	3·73	0·07	0·25	1·11	1·43	

The cost of the working and management of Indian canals is shown in great detail in the revenue accounts of the different works: the total charges are primarily divided into the subheads, "Revenue Management," "Maintenance of Works," and "Indirect Charges." The

[1] Lately opened.

first sub-head includes the cost of all establishments employed (both in the Public Works Department and, under the Collector, in the Civil Department) in the assessment and collection of Canal Revenues.

The second sub-head covers all the establishment charges, the cost of works and repairs, charges for tools and plant, and the upkeep of plantations, &c. The third sub-head is for various book charges—such as leave allowances and pensions—which are debited indirectly. The three sub-heads together make up the gross "Working Expenses." The statement given on the opposite page shows the cost of "Revenue Management" and "Working Expenses" on some of the principal irrigation works in India, and, at the foot of it, the average, which includes all works, great and small, is given.

If this table is compared with the similar one given on page 266 of the previous edition of this book it will be seen that, in the twelve years which have elapsed, the incidence of irrigation revenue per acre—that is, the gross water rates—have increased considerably. In nearly all cases the cost of revenue management and the total working expenses have decreased—in some cases they have decreased largely—the result being, of course, a material increase in the net revenue. The Orissa System still stands out prominently as the one in which the cost of revenue management exceeds that of all others, a fact which is partly due to the extremely low water rate which is charged on those canals, and the very large number of cultivators with whom the collecting establishment has to deal.

The Mutha Canal in Bombay, which is the most expensive of all per irrigable acre, derives a considerable income from the supply of water for drinking purposes in Poona, and the cost per acre would be considerably modified if this circumstance were fully taken into account. The

COST OF PRINCIPAL PRODUCTIVE IRRIGATION WORKS TO THE END OF MARCH, 1903.

Province.	Name of Works.	Approximate Full Discharge of Canals.	Area Irrigable.	Cost.	Cost per Acre Irrigable.
		Cubic Feet per Second.	Acres	Rupees.	Rupees.
Burma	Mandalay Canal	1,500	89,000	46,06,719[1]	52
	Swebo Canal	2,600	150,000	46,28,060[1]	31
Bengal	Orissa Canals	6,000	275 000	2,65,21,026	96
	Midnapore Canal	1,500	125,000	84,77,358	68
	Sone Canals	6,400	600,000	2,67,40,808	45
	Hijili Tidal Canal[2]...	—	—	26,15,154	—
United Provinces ...	Ganges Canal	8,000	1,300,000	3,04,16,325	23
	Lower Ganges Canal (including Fatehpore Branch)	5,000	1,244,000	3,97,42,115	32
	Agra Canal	2 000	312,000	99,15,523	32
	Eastern Jumna Canal	1,800	337,000	42,74,934	13
Punjab	Western Jumna Canal ..	6,400	809 000	1,72,51,501	21
	Bari Doab Canal	6 500	849 000	1,95,85 680	23
	Sirhind Canal	8,200	1,170 000	2,46,52,228	21
	Upper Sutlej (including Lower Sohag and Para Canals)		349,700	17,01,510	5
	Chenab Canal	10,800	1,600,000	2,75,09,322	17
	Sidhnai Canal	2,400	195,000	12,91,905	6
	Jhelum Canal	3,800	266,500	1,14,68,942	43
Madras	Godavery Delta System	8,500	670,000	1,33,75,002	20
	Kistna Delta System	8,700	550,000	1,43,96,664	26
	Penner River Canals	7,000	145,500	62,61,861	43
	Cauvery Delta System		919,500	30,70,196	3[3]
	Srivaikuntam Anicut System ...	2,400	27,800	15 01,625	54
	Kurnool Canal	1,500	58,700	2,17,56,052	371
	Barur Tank	—	5,800	4,31,260	74
	Periyar Reservoir System...	—	110,900	89,87,572	82
Bombay (Sind) ..	Desert Canal	3,700	130 000	25,91,395	20
	Unharwah...	2,300	56,000	6,50,223	12
	Begari Canal	5,500	186 500	17,06,799	9
	Eastern Nara Works	—	309,700	63,95,139	21
	Jamrao Canal	3,200	254,100	83,07,240	33
	Dad Canal	3,200	145,400	21,27,750	15
Bombay (Deccan and Gujarat)	Hathmati Canal	—	8,000	5,17,838	65
	Lower Panjrah River Works .. .	—	12,600	4,68,621	37
	Kadva River Works	—	14,600	7,97,905	55
	Lakh Canal	—	11,300	3,71,891	33
	Mutha Canals	—	16,800	68,26,335	406
	Ekruk Tank	—	16,900	13,40,386	79
	Krishna Canal	—	12,300	8,64,892	70
Average cost per acre (excluding the Kurnool and Mutha Canals) of all the Works					24 6

very high cost per acre of the Kurnool Canal is misleading. The canal as an irrigating work is a failure, as the water is not needed over a great portion of the area which could, otherwise, be irrigated. The general result, however, is sufficiently accurate, and it may be said that the works of this class cost on the average about Rs. 24·6

[1] Incomplete: estimated cost (direct charges) given. [2] Navigation work only. [3] Capital nominal—a very old work.

for each acre irrigable. The cheapest of the eleven large works[1] is the Cauvery system of canals in Madras; but the circumstances of this system are peculiar, as the irrigation of the Cauvery delta is carried out to a large extent through the agency of natural channels, and it cannot be taken as a representative case. The other ten large works—that is, works designed to irrigate about half a million acres or more—will cost on the average Rs. 27 per irrigable acre. Of these works the most expensive is the Orissa system in Bengal, which cost Rs. 96 an acre. This system is not in itself a successful one, and large sums were spent in making the canals navigable. The cheapest of the large systems is the Chenab Canal, which is also the most recent: its ultimate cost per acre will probably be less than Rs. 17, as it will irrigate more than the figure given in the statement.

It has been explained that the Major Works (A) are works which are expected to be remunerative. That is, they are expected to give a net revenue greater than the interest paid by Government on the money borrowed for their construction. Taken collectively they fulfil this condition abundantly: although individual works, and even the groups of works in three of the seven provinces fail to do so. Regular accounts have been compiled from the commencement, which have been annually credited with the net revenue and debited with the interest charges. The aggregate results are shown in the following table. This shows that up to the present

MAJOR WORKS (A).—PRODUCTIVE WORKS.

Province.	Number of Works which have not Paid.	Number of Works which have Paid.	Total Gain or Loss from the Commencement to Date.
			Rupees.
Burma...	2	0	6,63,394 loss
Bengal	4	0	6,50,87,512 loss
United Provinces	3	2	3,52,33,562 gain
Punjab	2	5	6,91,89,928 gain
Madras	3	5	7,88,14,543 gain
Bombay (Sind)	5	4	58,56,011 gain
Bombay (Deccan and Gujarat)	0	7	87,48,880 loss
Total	19	23	11,45,94,258 gain

time only twenty-three of the forty-two works have worked at a profit of more than 4 per cent., but that the profits from these twenty-three have been sufficient to cover the deficiencies on the other nineteen. The net result is that the works of this class have covered the interest charges with a gross excess to the credit of Government of nearly 12 crores of rupees, and the profit is increasing largely every year. Among the nineteen works which have not, so far, covered the gross interest charges on their capital cost, there are nine or ten[2] which are never likely to do so, but the others will probably be financially successful. Five or six are not in full operation as yet. Among the twenty-three works which have more than covered their interest charges, there are four which stand out, prominently, as most successful. These are the Eastern and Western Jumna Canals, the Godavery, and the Cauvery Canals. The surplus revenue from these four works alone is about 1,330 lakhs of rupees: they are all works which had existed in a more or less crude form before they were taken in hand by the British Government. The modern works, which have been entirely constructed by the British

[1] Orissa, Sone, Ganges, Lower Ganges, Bari Doab, Western Jumna, Sirhind, Chenab, Godavery, Kistna, and Cauvery Canals.

[2] Three canals in Bengal, one in Madras, five or six in the Deccan and Gujarat.

Government in the last thirty years, were for a time a drain upon the finances rather than a support to them. The following statement shows the improvement which has taken place in the last twelve years in some of the works :—

Canal.	Percentage of Net Revenue on Capital Outlay.	
	1891.	1903
BENGAL :—		
Sone Canals...	0·10	3·27
UNITED PROVINCES :—		
Ganges Canal	7·10	10·51
Lower Ganges Canal	2·00	3·77
Agra Canal	4·00	6·16
PUNJAB :—		
Bari Doab Canal	8·07	12·8
Sirhind Canal	4·05	7·68
Chenab Canal	0·08	21·26

The policy of constructing irrigation works from borrowed funds was initiated in 1869. At that time about 600 lakhs of rupees had been expended on the fourteen Major Works (A) which were at that time in operation[1]: since then some 600 lakhs more have been spent upon them. From 1869 to 1878 was a period of great activity in the construction of irrigation works. During that period about 1,100 lakhs of rupees were expended, and eleven works[2] came into operation. From 1879 to 1888 the expenditure gradually decreased: about 720 lakhs of rupees were spent in that decade, of which 20 lakhs were for the purchase of the Kurnool Canal; during that period seven works[3] were added to the list of canals in operation. From 1889 to 1898 about 800 lakhs of rupees were expended, and one work[4] only was opened for irrigation. From 1899 to 1903 the expenditure on works of this class was about 400 lakhs of rupees, and six works[5] were added to the list, and, in addition, there were three works,[6] under construction, which had not come into operation.

[1] United Provinces: Ganges, Eastern Jumna.
Punjab: Bari Doab, Western Jumna.
Madras: Godavery, Kistna, Cauvery, Penner.
Bombay: Lower Panjhra, Kadva River.
Sind: Desert, Unharwah, Begari, Eastern Nara. } ... ... 14 Works.

[2] Bengal: Orissa, Midnapore, Tidal, Sone.
North-Western Provinces: Agra.
Madras: Srivaikuntam.
Bombay: Hathmati, Pravara River, Mutha, Ekruk Tank, Krishna. } 11 Works.

[3] United Provinces: Lower Ganges.
Punjab: Sirhind, Lower Sohag and Para, Sidhnai, Chenab.
Madras: Kurnool, Barur. } ... 7 Works.

[4] Madras: Periyar... ... ... 1 Work.

[5] United Provinces: Fatehpore Branch.
Punjab: Jhelum.
Sind: Jamrao, Dad, Mahiwah.
Burma: Mandalay. } ... ... 6 Works

[6] Sind: Naulaki, Nasrat.
Burma: Swebo. } ... ... 3 Works.

Total ... ... 42 Works.

The fourteen old works which were in operation before 1869 are now paying 12 per cent. on the capital cost. The twenty-three works which have been in operation from thirty to forty years are paying over 9 per cent., and the works which have been in operation from ten to

STATEMENT OF FINANCIAL RESULTS OF THE PRINCIPAL MAJOR WORKS (A) (PRODUCTIVE WORKS) IN 1902—1903.

Province.	Year when Revenue was First Collected.	Name of the Works.	Capital Outlay at End of the Year.	Gross Revenue of the Year.	Working Expenses.	Net Revenue.	Percentage of Net Revenue on Capital.	
			Rupees.	Rupees.	Rupees.	Rupees.		
Burma ...	1902	Mandalay Canal	46,96,764	24,859	33,526	- 8,667	loss	loss
	—	Swebo Canal	20,07,584	—	—	—	—	
Bengal ...	1869	Orissa Canals	2,65,21,026	4,03,848	3,89,204	14,644	0·05	1 5
	1869	Midnapore Canal	84,77,358	2,23,678	1,52,452	71,226	0·84	
	1875	Sone Canals	2,67,40,808	14,45,780	5,71,763	8,74,017	3 27	
	1869	Hijili Tidal Canal (Navigation only)	26,15,154	41,050	36,265	4,785	0·18	
United Provinces ...	1855	Ganges Canal	3,04,16,325	43,94,084	11,96,862	31,97,222	10·51	7·4
	1879	Lower Ganges Canal...	3,62,50,827	24,89,682	11,21,601	13,68,081	3 77	
	1874	Agra Canal	99,15,523	8,79,371	2,68,828	6,10,543	6 16	
	1830	Eastern Jumna Canal	42,74,934	16,06,395	5,38,955	10,67,440	24 97	
	?	Fatehpore Branch (L. Ganges Canal)	34,91,288	1,32,345	1,28,287	4,058	0 12	
Punjab ...	1821	Western Jumna Canal	1,72,51,501	23,49,819	8,64,073	14,85,746	8 61	11 4
	1859	Bari Doab Canal	1,95,85,680	35,12,861	9,93,844	25,19,017	12·86	
	1883	Sirhind Canal	2,46,52,228	27,81,123	8,87,610	18,93,513	7 68	
	?	Upper Sutlej (including Lower Sohag and Para) Canals	17,01,510	4,86,794	3,80,052	1,06 742	6 27	
	1887	Chenab Canal...	2,75,09,322	72,54,165	14,06,286	58,47,879	21 26	
	1886	Sidhnai Canal...	12,91,905	1,92,022	1,40,968	51,054	3 95	
	1902	Jhelum Canal	1,14,68,942	37,810	1,49,840	- 1,12,030	loss	
Madras ...	1846	Godavery Delta System	1,33,75,002	32,28,810	7,66,030	24,62,780	18 41	9·3
	1855	Kistna Delta System	1,43,96,664	29,46,463	6,69,514	22,76,949	15·81	
	1860	Penner River Canals...	62,61,861	3,92,040	78,153	3,13,887	5 01	
	1836	Cauvery Delta System	30,70,196	9,73,123	99,160	8,73,963	28 46	
	1870	Srivaikuntam Anicut System ...	15,01,625	1,22,482	30,332	92,150	6·13	
	1882[1]	Kurnool Canal	2,17,56,052	2,03,416	90,441	1,12,975	0 52	
	1887	Barur Tank	4,31,260	11,109	4,937	6,172	1·43	
	1896	Periyar Reservoir System	89 87,572	4,81,786	1,54,199	3,27,587	3 64	
Bombay (Sind) ...	1853	Desert Canal	25,91,395	2,03,908	1,09,099	94,809	3 66	4 8
	1885	Unharwah Canal	6,50,223	1,12,596	36,859	75,737	11 65	
	1855	Begari Canal	17,06,799	3,79,645	1,09,337	2,70,308	15 84	
	1854	Eastern Nara Works...	63,95,139	5,53,011	1,19,761	4,33,250	6 77	
	1899	Jamrao Canal	83,07,240	5,57,713	2,42,733	3,14,980	3 79	
	1901	Dad Canal	21,27,750	1,02,662	1,28,754	- 26,092	loss	
Bombay (Deccan and Gujarat)	1873	Hathmati Canal	5,17,838	516	6,626	- 6,110	loss	1·8
	1866	Lower Panjra River Works... ..	4,68,621	15,936	8,717	7,219	1 54	
	1868	Kadva River Works	7,97,905	8,267	6,375	1,892	0 24	
	1869	Lakh Canal	3,71,891	778	1,715	- 937	loss	
	1873	Mutha Canals...	68,26,335	2,97,835	1,34,750	1,63,085	2 39	
	1872	Ekruk Tank	13,40,386	19,355	12,098	7,257	0·54	
	1869	Krishna Canal...	8,64,892	46,751	14,796	31,955	3 69	
						Total percentage for all Major Works (A)	7 37	

twenty years are paying over 7 per cent. The statement on this page gives the main revenue statistics of all the forty-two Major Works (A), and it will be seen that in 1902—1903 these forty-two works, including the good, bad, and indifferent ones and those not in operation, paid, in the

[1] Date of the purchase of the canal by Government.

aggregate, 7·37 per cent. on their gross capital outlay. The works in Bengal and Bombay are never likely to be financially successful except the Sone Canals, which are yearly giving better results: but there is every prospect of improvement in all the other provinces, and there is little doubt that these forty-two productive works will, as they develop, pay considerably more than they did in 1902—1903.

MAJOR WORKS (B).—PROTECTIVE WORKS.

The works of this class, which are eleven in number, are entirely of modern origin: the amount expended on them and the financial results of 1902—1903 are shown in the following statement:—

Province	Year in which Revenue was First Received.	Name of Work.	Capital Outlay at End of the Year.	Gross Revenue of the Year.	Working Expenses.	Net Revenue.	Percentage of Net Revenue on Capital.
			Rupees	Rupees	Rupees.	Rupees.	
Central Provinces	—	Khyrbanda Tank	31,743	—	—	—	—
Bengal	—	Dhaka Canal ...	2,01,910	—	—	—	—
		Trebeni Canal ...	6,26,236	—	—	—	—
United Provinces	1885	Betwa Canal ...	45,44,011	1,06,743	1,30,601	-23,858	loss.
N. W. Frontier...	1885	Swat River Canal	41,66,252	5,29,628	88,813	4,40,815	10·58
Madras	1893	Rushikulya Project	48,97,366	1,02,594	72,701	29,893	0·61
Bombay (Deccan and Gujarat)...	1884	Mhasvad Tank ...	20,88,427	15,200	14,842	358	0·02
	1885	Nira Canal ...	56,88,737	2,31,596	47,704	1,73,892	3·06
	1901	Shetphal Tank ...	6,71,519	843	714	129	0·02
	Incomplete	Chankapur Tank	1,12,352	—	—	—	—
	Incomplete	Maladevi Tank ...	3,25,528	—	—	—	—

The works are not expected to pay 4 per cent. on their capital cost, but the Swat River Canal, which is in several respects rather a remarkable work, has shown the same rapid development of irrigation which has characterised most of the works in the Punjab: it has irrigated far larger areas than were anticipated, and it has already proved to be a remunerative work. It has, on the whole, paid more than 4 per cent., and for some years past has paid 10 per cent. on its capital cost. It was primarily undertaken, chiefly on political grounds, in order to settle the lawless tribes residing in the north-east corner of the Peshawur valley where the canal lies.

MINOR WORKS (A).

The eighty-five works of this class which are in operation are of a more varied character than the major works; they comprise perennial canals, inundation canals, navigation canals, reservoirs, tanks, embankments, and one work for the supply of drinking water. About one-fourth of the works were originated by native rulers, the predecessors of the British in the government of the country, and have been taken up and improved by the British Government. In some cases the capital account is rather questionable, as the value of the old native works has not been included. The statement on next page shows the number and cost of the works by provinces, and the financial results obtained in the last year of which the statistics are available.

The works which are in operation in this class comprise about 6,500 miles of irrigation canals and distributaries, and about 1,200 miles of navigable canals and channels. These works are all practically completed.

MINOR WORKS (A).—WORKS OF WHICH CAPITAL AND REVENUE ACCOUNTS ARE KEPT. FIGURES FOR THE YEAR 1902—1903.

Province.	Number of Works.	Class of Works.	Capital Outlay.	Gross Revenue.	Working Expenses.	Net Revenue.	Percentage on Capital Outlay.
			Rupees.	Rupees.	Rupees.	Rupees.	
Rajputana ...	3	Tanks	20,89,122	1,08,809	70,876	37,933	1·23
Baluchistan ...	3	One reservoir system, two canals	16,93,911	8,145	17,641	-9,496	—
Burma	3	Embankments	34,53,416	11,80,138	2,14,393	9,65,745	27·97
Bengal	3	One irrigation canal and two navigable canals	1,23,65,696	4,12,104	2,85,948	1,26,156	1·02
United Provinces	4	Irrigation canals ...	31,69,516	3,23,017	2,35,412	87,605	2·76
Punjab... ...	3	Irrigation canals ...	13,01,719	4,73,808	3,69,679	1,04,129	7·99
N.-W. Frontier	1	Irrigation canal ...	4,78,733	1,46,984	37,120	1,09,864	22·95
Madras... ...	32	One water supply system, twenty-seven small irrigation systems, four navigable canals ...	1,98,20,839	11,48,641	4,36,065	7,12,576	3·60
Bombay (Sind)	7	Irrigation works ...	41,70,417	12,01,244	3,47,560	8,53,684	20·47
Bombay (Deccan and Gujarat)...	26	Small irrigation works	1,17,84,376	13,10,482	4,29,070	8,81,412	0·36
Total ...	85	Total ...	5,71,57,358	51,12,128	20,96,204	30,15,924	5·28

Three of the works, the Calcutta and Eastern Canals, the Orissa Coast Canal, and the Buckingham Canal, are extensive systems of navigation on the east coast; they comprise about 1,050 miles of navigable channels. Of these three the first alone is worked at a profit; it is an old work.

It will be seen that the Minor Works (A) pay over 5 per cent: they owe their success mainly to the Irrawaddy embankments in Burma, and to the inundation canals of Sind and the Punjab: although there are other works which give more than 4 per cent. The numerous small works in Bombay are unremunerative, and there is but little hope that the returns derived from them will materially improve. The works in this class, which were taken over by the British Government in a more or less developed condition, were chiefly the inundation canals of the Punjab and Sind and the Rajputana tanks: the remunerative results of this class of works, as a whole, is no doubt partly due to the fact that the capital account does not take cognisance of the value of the works when they were acquired. But, on the other hand, it must not be forgotten that the works have been largely extended, altered, and improved by the British Government, and that, in some cases—as on the river Indus in the Punjab and Sind—lines of embankment are maintained at the expense of the canals, which not only protect the irrigated areas, but are often of considerable value for other purposes quite unconnected with the sources from which the revenue credited to the canals is realised.

MINOR WORKS (B).

The Minor Works (B), although generally works of little importance from an engineering point of view, are of considerable value both to the agricultural and financial interests of the country. There is no capital account of any of them, and the cost of the great majority is quite unknown, as they existed long before they were taken in hand by the British Government: a revenue account is only fully kept in a few cases. The works in Bengal consist of two new

canals, partly for irrigation and partly for water-supply purposes, which are not financially remunerative, and one system of navigation, through river channels conserved for the purpose, which has a considerable net revenue. The works in the Punjab are old inundation canals. The Madras works of this class include over 28,000 small tanks and 6,000 irrigation channels, the repairs and improvements of which are undertaken by Government. It will be noticed from the statement at the foot of this page that these works, though comparatively unimportant individually, irrigate in the Madras Province, in the aggregate, more than the major works in the deltas of the great rivers. The revenue derived from these works is mainly a share of land revenue, which is credited in the accounts of the Empire with the land revenue, and the direct receipts from them only amount to 7 or 8 lakhs of rupees a year. When credit is given for receipts from all sources these Minor Works (B) bring in a net revenue to the State of about 50 to 60 lakhs of rupees a year after all charges are deducted.

The financial results of all classes of irrigation works in India which are under the control of Government are given in the following statement, which refers to the year 1902—1903 and only takes cognisance of works which are open for irrigation:—

Class of Works.	Capital Outlay	Net Revenue.	Percentage on Capital.
	Rupees	Rupees	
Major Works (A). Productive Works...	37,58,04,788	2,78,02,602	7·4
Major Works (B). Protective Works.	2,20,56,312	6,21,229	2·82
Minor Works (A)	5,71,57,358	30,15,924	5·28
Minor Works (B) . .	Not known.	54,18,552	—
Total	45,50,18,458	3,68,58,307	—

The profit on the three first classes amounts to 6·91 per cent. on the capital outlay on them.

The areas irrigated in the various provinces in 1902—1903 by the different classes of works administered by Government are shown in the following statement:—

Province	Major Works (A) Productive Works	Major Works (B) Protective Works	Minor Works (A)	Minor Works (B)	Total.
	Acres	Acres	Acres	Acres	Acres.
Rajputana	—	—	26,199	—	26,199
Baluchistan	—	—	2,939	—	2,939
Burma	7,223	—	437,729	407,291	852,243
Bengal	796,029	—	—	39,425[1]	835,454
United Provinces ..	2,241,723	64,457	137,375	—	2,443,555
N.-W. Frontier Province	—	173,772	—	—	173,772
Punjab	4,864,274	—	240,719	547,139	5,652,132
Madras	2,848,554	92,399	584,081	3,436,651	6,961,685
Bombay (Sind) ...	1,072,001	—	791,530		
Bombay (Deccan and Gujarat)	22,865	39,177	38,237	891,900	2,858,710
Total	11,852,669	369,805	2,261,809	5,322,406	19,806,689

[1] This figure is doubtful.

The area annually irrigated by the works classed as "Minor Works (B)" shows no material increase on the whole, although there are fluctuations in the areas according to the seasons: but the three more important classes of works are developing steadily, as the following statement shows:—

Period.	Major Works (A). Productive Works.	Major Works (B). Protective Works.	Minor Works (A).	Total.
	Acres.	Acres.	Acres.	Acres.
Annual Average of the three years ending March, 1896	7,099,725	168,957	2,467,520	9,736,202
Annual Average of the three years ending March, 1899	10,207,091	311,713	2,685,034	13,203,838
Annual Average of the three years ending March, 1902	11,213,141	336,028	2,531,417	14,080,586
Irrigated in the year ending March, 1903	11,852,669	369,805	2,261,809	14,484,283

The total shows an increase of nearly 50 per cent. in the last seven years.

The rates which are charged for the use of water for purposes of irrigation vary largely in different parts of India and for different crops. In some cases a charge is made for a single watering, and in others a special rate is imposed for water taken during certain months, but generally the charge is an acreage rate for irrigating the crop to maturity. Excluding very exceptional cases, it may be said that this rate varies from 1 rupee an acre for rice crops in some parts of Bengal and Sind up to 20 rupees[1] an acre, which is not an extreme rate in Bombay for sugar-cane crops. The average rates in the different provinces, including enhanced land revenue and all similar charges made on account of the water supplied, are shown in the following statement. The average rate for the whole of India is rather more than 3 rupees an acre for the revenue realised and 1 rupee an acre for working expenses:—

Province.	Average Value of Crops per Acre.	Major Works (A). Productive Works.		Major Works (B). Protective Works.		Minor Works.	
		Revenue Realised per Acre Irrigated.	Working Expenses per Acre Irrigated.	Revenue Realised per Acre Irrigated.	Working Expenses per Acre Irrigated.	Revenue Realised per Acre Irrigated.	Working Expenses per Acre Irrigated.
	Rupees.	Rupees.	Rupees.	Rupees.	Rupees	Rupees	Rupees.
Rajputana	—	—	—	—	—	4·15	2·71
Baluchistan	—	—	—	—	—	2·77	6·00
Burma	25·0	3·44	4·64	—	—	2·69	0·50
Bengal	34·3	2·61	1·40	—	—	—	—
United Provinces ...	36·3	4·24	1·45	1·66	2·03	2·35	1·71
Punjab	26·8	3·71	1·08	—	—	2·01	1·57
N.W. Frontier Province	26·3	3·05	0·51	—	—	—	—
Madras	25·7	2·93	0·66	1·11	0·78	1·84	0·58
Bombay	103·8	2·12	0·89	6·29	1·86	1·57	0·52

The percentage which the rate charged for the water bears to the value of the crops is, theoretically, a gauge of the severity of the charge on the cultivator. Gauged by this standard

[1] A rate of 50 rupees per acre has actually been realised in the immediate neighbourhood of Poon.

the Bombay rate of 6·29 rupees per acre, which appears to be high, is shown to be moderate, and this is really the fact when the very high value of the sugar-cane crop in that province is taken into account. The Bengal rates, which are only about 7 per cent. on the value of the crops, are known to be capable of enhancement without hardship. The Madras rates[1] are far the highest of all with reference to the value of the crops; this is partly due to the very low average value of the crops in Madras in consequence of the almost exclusive cultivation of rice by irrigation from the canals, but it is also due to no small extent to good administration and efficient technical management. The very low rates charged in Bengal are partly due to the fact that irrigation in that province is not as much required as elsewhere; partly—indeed, in no small degree—to the fact that the system of land settlement in that province is such that the landlords absorb a portion of the profits which in other provinces are realised by Government and credited to the revenue accounts.

The chief crops which are watered by the canals are sugar-cane, wheat, rice, and cotton. In Burma, Bengal, and Madras from 80 to 90 per cent. of the irrigated crop is rice. In Sind the rice crop is about 30 per cent. of the irrigated area, while in the Deccan, in the Punjab and the United Provinces, the percentage of rice is from 4 to 8 per cent. only. Sugar-cane is about 11 per cent. of the crop in the United Provinces and the Deccan, 3 per cent. in the Punjab, and 8 per cent. in Bengal. Wheat is the great crop in the Punjab and United Provinces, where about 40 per cent. of the irrigated area is under that crop; in Bombay only 5 to 10 per cent. is wheat, and in Bengal it varies from 3 per cent. to 15 per cent.; in Madras it is absent. Cotton amounts to some 7 to 10 per cent. of the irrigation in the Punjab, and 3 or 4 per cent. of that in the United Provinces; there is some in Bombay also.

The value, per acre, of the irrigated crops, taken from the last returns available, is given in the following statement:—

Province.	Value per Acre of Irrigated Crops.			
	Sugar-cane.	Wheat.	Rice	Cotton.
	Rupees.	Rupees.	Rupees.	Rupees.
Bengal	30	23	33	—
United Provinces ..	83	29	42	28
Punjab	107	30	37	29
Madras	—	—	27	—
Bombay (Sind)	—	27	16	—
Bombay (Deccan and Gujarat)	177	21	26	10

The capital cost of the works in operation of which capital accounts are kept was about 45 crores of rupees, or £30,000,000 sterling, at the end of the years 1902—1903. In that year the value of the crops irrigated by these works was about 40 crores of rupees, say, £26,000,000. Taking all the circumstances into consideration, it may be safely said that one-third of this sum —say, £9,000,000 sterling—represents the increased value of the crops due to the irrigation; for this increase in the value of the out-turn the people paid about £3,000,000 in water rates.

These are the facts in ordinary years of normal rainfall. In years of famine the facts are very different. The increment in the crop due to irrigation is then vastly greater. For instance, in the famine year of 1896—97 the Author visited many parts of the Sone Canals in

[1] Except in Burma, where the area is comparatively small.

Bengal. He saw luxuriant crops where the canal water had irrigated the lands, while, only a few hundred yards away, the fields were parched and dry and the crop was ruined and valueless. This occurred in many places. In that year the capital cost of the Sone Canals stood at Rs. 2,68,97,368, the value of the crops matured by the canal was Rs. 2,66,62,086. The percentage of the crop which was saved by the irrigation was at least 60 per cent. of the whole, so that in that one year the value of the canal to the cultivators was 60 per cent. of whole capital cost of the works, or, say, Rs. 1,60,00,000. For that they paid in water rates Rs. 11,24,449, or only 7 per cent. of the increment which the canals had given them. This is the bare money value which accrued, but when the saving in suffering, sickness and poverty is taken into account, the benefits of irrigation works in years of famine need no advertisement to the people of the tracts which benefit by it.

These figures display, perhaps more forcibly than any others, the magnitude of the agricultural interests which are bound up with the Irrigation Works of India. The extent to which the perfection of the irrigated crops is dependent on irrigation varies greatly with the climatic conditions of the different provinces, and in all provinces according to the incidence of the rainfall during any particular season. In Sind and in some parts of the Punjab, where the rainfall averages about 3 or 4 inches, or even less, in the year, the crops are at all times dependent on the canals; they could not be grown at all unless water were supplied for irrigation. In Bengal, on the other hand, where the rainfall varies from about 40 to 50 inches, and is usually well distributed with reference to the necessities of the crops, the rice crops (80 per cent. of the whole area) can, in all ordinary years, be matured without irrigation at all, although, even in ordinary years, it has been proved that the irrigated crops give a better out-turn than unirrigated ones by about 20 per cent. In Bombay also the conditions are somewhat similar. In these provinces the value of the irrigation works becomes apparent only in the years of famine and drought. In such years it occasionally happens that the crop withers almost entirely when irrigation cannot reach it. At such times an irrigation work which has cost, say, 25 rupees an acre, and which can ensure crops worth, say, 30 rupees an acre, finds, in the eyes of the cultivators at any rate, ample excuse for its construction, even although, as is unfortunately the case with all the irrigation works of Bengal and Bombay, the financial results are unsatisfactory when viewed in the light of the Government accounts.

It has not infrequently been assumed that the probabilities of the success of a new irrigation project can be gauged by a consideration of the incidence of the rainfall on the tract commanded. The rainfall is no doubt one of the chief factors to be considered; but the statistics show conclusively that there must be other factors of at least equal, if not of greater, weight, which must be taken into account in estimating the success or failure of an irrigation system. For example, the annual rainfall in that portion of Bombay where the irrigation works lie is scanty, while that in Madras is copious, but in the former case the irrigation works are unremunerative, whereas in Madras they are, with one exception, most lucrative. Even a more striking instance can be found in Madras itself; the Cauvery Canals, which are most remunerative, lie in a district where the average rainfall is about 45 inches in the year, whilst the Kurnool Canal, which is the most conspicuous failure of all irrigation works in India, lies within 300 miles of the Cauvery in the same province, in a tract where the average rainfall is less than 30 inches. In this case the difference in the nature of the soil is one reason for the difference in the results; but the causes which produce these striking differences are not thoroughly understood, and the available statistics afford but slight clue to them. It may, however, be said that in Madras the temperature is generally so equable that it is possible to grow two and even three crops of rice on the same field during the year: this is not possible in the more variable climates.

It may be that this climatic difference explains the great discrepancy in the results obtained in Madras and in the neighbouring province of Bengal, where the profits realised are small. It should also be noted that the actual amount of the rainfall is of less importance than its distribution. Differences in soil and in methods of cultivation have also great weight in determining the success of an irrigation project, and it is by no means improbable that the different systems of land tenure which are in force in different parts of India have a powerful influence in this matter. There is little doubt that the *ryotwari* system of the Punjab lends itself much more readily to the system of irrigation from large canals than the more obstructive *zemindari* system of Bengal. Whatever the causes may be which should determine the results obtained, it must be admitted that much ignorance has prevailed concerning them, and this has led to the construction of some works which have signally failed to produce the results which were anticipated by their projectors.

It is now fully admitted in India that the financial test is not the only one—or, indeed, the ruling one—which should be applied in order to determime whether a particular irrigation work should be constructed or not. The value of irrigation works in protecting particular tracts from famine has a political, administrative, and humanitarian value which cannot be gauged in money. The Irrigation Commission of 1901—1903 reported in favour of the construction of works which would cost not less than 44 crores of rupees and would result in an increase of 6½ million acres in the irrigated area. It was estimated that the construction of these works would impose a permanent yearly burden of nearly 74 lakhs of rupees on the State. Against this would have to be set, however, the reduction in the cost of future famines resulting from the construction of the works, which was estimated at 31 lakhs a year.

In the Punjab there are two large tracts which remain to be brought under irrigation. The first covers an area of 1,600,000 acres in the Montgomery and Maltan districts, about one-half of which is Crown waste land.[1] It is proposed to irrigate this by canals from the Chenab river, the cold-weather supply being augmented by a feeder from the Jhelum. The second tract is the great Sind Sagar Doab, which comprises an area of 5 million acres, lying to the south of the Salt range of hills and bounded by the Indus on the west and the Jhelum and Chenab on the east. The whole of this country might be commanded by a canal taking off from the Indus at Kalabagh.

In Sind there is much room for irrigation works which would probably be very remunerative. Here, as in the Punjab, irrigation has completely altered the face of the country, and has converted barren wastes into fertile fields. It has been suggested that a weir should be constructed across the Indus at Sukkur, and it is contended that that will be rendered necessary, sooner or later, by lowering of the water level in the river, due to the large draught made by the new Punjab Canals on the waters of the Indus. The cost and engineering difficulties of such a scheme would be very great, but the results would be highly beneficial.

In Bombay and the Deccan the existing works are so unremunerative that great hesitation is felt in advocating new schemes. But there is no part of India so liable to severe famines, and the protective effect of irrigation works is much needed. The rainfall of the Western Ghâts provides a copious supply, and, although there is little prospect of large extension, it is probable that works for storing the rainfall will be undertaken as a protection against famine.

In Madras there is still a wide scope for the extension of irrigation, but in most cases storage works would be necessary. The supplies of even the great Kistna and Cauvery rivers are often insufficient for the area at present dependent on them, and proposals have been made to form large reservoirs on both rivers. There are large tracts in the Bellary, Anantapore, Kurnool, Cuddapah and Nellore districts, which are peculiarly liable to severe famines. These can on.

[1] See pages 22 to 24.

be protected by the construction of storage works of vast capacity on the Tunga and by the completion of the project originally proposed by Sir Arthur Cotton.

In the United Provinces the field for extension of irrigation works is not for the irrigation of the Oudh districts from the Sardah river has been frequen set aside for various reasons. Protection from famine is most urgently requir which lie to the south of the river Jumna, but the supply of water is insufficie

In Bengal there is some scope for protective works in those districts o subject to famine. But the supply of water is, in most cases, precarious.

The Government of India has now under consideration the proposals made Commission of 1901—1903, and it is believed that the result will be the establishm of steady progress in the construction of the most necessary works. The annual the construction of works has been increased of late years, and will, it is hoped, be augmented. The statistics given in this chapter show that, viewed from the point the Government Treasury, there can be no doubt of the advantage derived from th tion works. The landowners derive a benefit from the works by the increased rental they obtain,[1] while the cultivators of the fields have at least equal reason to be satisfied w result, for the out-turn of their fields is not only ensured in years of drought, but the of produce is very largely increased even in ordinary years, at a cost to them which ma roughly stated to be about 30 per cent. of the increased out-turn. In addition to the adv tages which accrue to those most immediately concerned, there are the many indirect advanta which follow from the large increase in the food supply of India which the irrigation works affor and from the absolute security which is obtained in many parts of the country where, without irrigation, the crops are, at the best, both inferior and precarious.

The British Engineers who have done much, and hope to do much more, to extend irrigation works in India, look with some pride on the fact that their works are not only remarkable from a purely professional point of view, but are successful financially and economically. The rulers of India regard these works, perhaps from a somewhat different point of view. They see in them not only a profitable property, a sound financial investment, but, far better, an active force ever potent to tie the population to their rulers, to render them happy in their homesteads and contented with their surroundings; a condition which cannot but tend to political advantage and security. The Swat River Canal, on the borders of the Punjab, has probably done more in ten years to still the turbulence of a quarrelsome frontier tribe, than all the police of the Province could have done in half a century. The Chenab Canal, which has provided new and prosperous homes for more than a million inhabitants, has done more to convince those colonists of the beneficial intentions of British rule than the Queen's Proclamation of 1858 and than all the resolutions of the Indian Government since Queen Victoria assumed the sovereignty of the country.

[1] The Famine Commission reported in 1880, para. 9, p. 151, that "the ordinary rental of land in Northern India is doubled by irrigation, while in eleven districts in Madras the average rental rises from Rs. 1.4.0 to Rs. 5.4.0 per acre when supplied with water. In Tinnevelly the increase is nearly tenfold. In the eight years preceding 1875—76 the average selling price of irrigated lands in the Cavari Valley of Mysore was 35*l.* an acre: the best 'dry' land at the same time did not fetch above 2*l.* or 2*l.* 10*s.*" It does not, of course, follow that the whole of this increase in value goes to the credit of the landlord.

INDEX.

A.

Absorption, 64
Beresford's rules for, in canals, 66
checked by silt, 66
difference of loss by, in different distributaries, 277
greatest in village channels, 66
loss per million square feet, 68
Administration, effective, in Madras, 318
of canal revenue, 305
Advances granted for construction of wells, 5
Afflux, 108, 110
Betwa Weir, 119
Jhelum Weir, 173
Narora Weir, 159
Okla Weir, 166
on Chenab Weir, 170
on Kali Nadi Aqueduct, 237
Sone Weir, 153
Agra Canal, 20, 157, 292, 306, 310
escapes on, 44
Weir, protective works, 166
Ajmere, evaporation and absorption in, 65
reservoir in, 96
Akbar, old canals, 13
Akhaijitgarh Reservoir, 89, 96
Alicante Masonry Dam, 85
Alignment of canals, contoured plan necessary, 286
on watershed, 286
of channels, main points affecting, 288
Alipur Regulator, Fuleli Canal, 213
Alluvial soil, 5
foundations in, 257
Ameen, 305
Analysis of sand, 35
of silt, 34
Ancient canals in Sind, 11
Anicut, the Baizwada, 15
Anicuts in Madras, 13
Aqueduct, Kali Nadi, 237
destruction of, 52
Kerai, on Midnapore Canal, 240
Solani, 236
Thapangaing, 238
Thorah Nullah in Bengal, 238
Archimedean screws, 4
Area commanded, proportion irrigated in Jhelum Canal, 18
irrigable by new projects in Punjab, 22
irrigated by inundation canals, 12
by a well, 4
in India, 2, 6, 20, 316
Midnapore Canal, 20
new projects in the Punjab, 22
Sone Canals, 20
Ashlar masonry not good on crests of weirs,
fine joints not good, 161
Ashti Reservoir, 94, 95
Tank, 9
flow-off, 61
loss by evaporation and absorption, 61
Assessment of irrigation, how made, 304
Assiut Barrage, 178
Automatic gates, Bhatgarh Reservoir, 198
cost of, on Lake Fife, 200
counter-balanced gates on Lake Whiting, Lake Fife, 196, 200
Lake Fife, 198
necessary on waste weirs of reservoirs, 196
of Lake Fife, worked in groups, 200
of waste weirs, 87
Reinold's, 196
Visvesvaraya, 198
Whitings, 196
shutters on Betwa Weir, 117
Average rainfall of India, 2
water-rates, 5

B.

Bahr Yusuf, 13
Baizwada Anicut, 15, 146
Balance beams, for lock gates, obsolete, 268
Baluchistan, Karez in, 10
Bandharas in Kandesh, 114
worked under village community, 116
Bareta Bund Reservoir, 96
Bari Doab Canal, 13, 17, 20, 22, 24, 45, 47, 67, 68, 108, 123, 272, 275, 292, 306, 310
Cascade Fall, 218
early falls on, 217
head-works, 124
instructive in silt question, 45
loss by evaporation and absorption in, 67, 68
rapids on, 218
very pretty canal, 124
Barol Reservoir, 96
Barrage, Assiut, 78
the Delta, in Egypt, 176
near Cairo, gates on, 194
Zifta, 178
Barur Tank, 8, 292, 310
Bau Masonry Dam, 85
Begari Canal, 11, 306, 310
"Bell's Bunds," in Chenab Weir, 167
Bengal, canals in, 19
cost of canals in, 309
development of irrigation in, 321
water-borne trade of, 255
"Beresford's filter," 174

..., 292, 314
...ad-works of, 116
...gulator and under-sluices of, 118

...shutters, 206
...4, 95
...n, 31, 33
... in, 96
...ashing sluices in, 86
...section of, 82
...ke Whiting Reservoir, 94, 95
...onry Dam, 82
...servoir, 81
catchment area of, 82
under-sluice shutters, 195
waste weir gates, 198
...Reservoir, 94, 95
...; inundation canals in, 11
...eservoir, 96
...a Tank Reservoir, 96
...ock" system of irrigation, 304
...lown up" syphon in Egypt, 244
syphons liable to be, 244
Bombay, development of irrigation in, 320
tanks, 9
and reservoirs, statistics of, 94
Borrow pits, silting-up by "in and out" system, 44
by "long reach" system, 44
by "internal silting," 44
to strengthen banks, 44
Boulders, hammer-dressed, make good floors, 124, 128
Breach in Mahanuddee Weir, 144
Breaches, damage greater than that due to spills, 103
Bridges on Indian canals, 227
Buckingham Canal, 251, 315
Budki Super-passage, pressure on foundations, 233
in Sirhind Canal, 233
Burma, cost of canals in, 309
Burra Bubsa Syphon, 244
Bye-wash from reservoir projects, 50

C.

CANALS, Agra, 20, 157, 292, 306, 310
Bari Doab, 13, 17, 20, 22, 24, 67, 68, 108, 123, 272, 275, 292, 306, 310
Barur Tank, 292, 310
Begari, 11, 306, 310
Bengal, 19
Betwa, 117, 292, 314
Buckingham, 251, 315
Cauvery, 15, 20, 306, 310
Chenab, 17, 20, 22, 24, 54, 167, 272, 276, 289, 292, 306, 310
Circular and Eastern, 251, 255, 315
Dad, 310
Desert, 292, 306, 310
Dhaka, 292, 314
Eastern Jumna, 13, 37, 108, 113, 126, 129, 272, 292, 306, 310
Eastern Nara, 12, 306, 310
CANALS, Fuleli, 11
Ganges, 19, 20, 34, 37, 68, 107, 132, 228, 254, 272, 283, 287, 292, 300, 306, 310
Godavery, 20, 306, 310
System, the, 16
Hathmati, 310
Jamda, 280
Jamrao, 11, 292, 306, 310
Jhelum, 18, 22, 57, 173, 292, 306, 310
Kadva River, 310
Khadva River Works, 292
Kistna, 20, 280, 306, 310
System, the, 15
Kurnool, 116, 291, 310
Lakh, 310
Lower Bari Doab, 245, 289
Lower Ganges, 19, 20, 110, 157, 272, 292, 306, 310
Lower Panjhra, 280, 310
Mandalay, 120, 239, 292, 310
Midnapore, 20, 292, 310
Mutha, 20, 67, 81, 292, 310
Nili, 10
Nira, 20, 67, 81, 87, 272, 280, 292, 314
Ojhar, 272
Orissa, 15, 19, 20, 292, 306, 310
Orissa Coast, 251, 255, 315
Penner River, 292, 306, 310
Periyar System, 306, 310
Rushikulya System, 63, 292, 314
Sarun, 104
Sidhnai, 138, 292, 310
Sirhind, 17, 20, 34, 35, 37, 39, 154, 228, 272, 276, 289, 292, 306, 310
Sone, 19, 20, 34, 37, 244, 272, 292, 306
Srivaikuntam System, 292, 310
Swat River, 306, 314
Swebo, 292, 310
Tidal, 310
Trebeni, 107, 244, 292, 314
Unharwah, 292, 306, 310
Upper Chenab, 22, 289
Upper Jhelum, 22, 289
Western Jumna, 126, 129, 272, 276, 292, 306, 310
alignment of, to avoid drainage, 228
ancient, in Sind, 11
area irrigated by, 2
constructed by Krishna Raya, sixteenth century, 13
cost of main and branch, 292
earliest in Upper India, 13
eleven irrigation systems also navigable, 252
extension of, in Punjab, influence on Sind Canals, 28
falls on, 217
inundation, 10, 25
navigation, statistics of, 252
perennial, 13
the most profitable system, 15
the oldest in the world, 13
theoretical sections of, 290
typical sections of, 290
water of, superior to well water, 28
weirs on, 217
Capital expenditure on Indian Canals, 309—315
Cascade fall on Bari Doab Canal, 218
Catchments, average flow-off from, 61—64
flow-off from, 50—61
maximum discharge from large, 52

INDEX.

Catchments, maximum discharge from small, 55—60
small, flow-off from, 54
Cautley, Sir Proby, and the Ganges Canal, 19
Cauvery Canal, 15, 20, 306, 310
River, 15, 21
Cavour Canal head-sluice, 206
Central Provinces, evaporation and absorption in tanks, 64
Centre sluices, Mahanuddee Weir, 144
Sone Weir, closure of, 151
difficulty of manipulation, 151
tumbler shutters on, 151, 152
Chankapur Reservoir, 94, 95
Tank, 314
Channels, alignment of, 286
dimensions of, 289
best form of, 45, 290
Chembrambaukam Tank, 7
Chenab Canal, 17, 20, 22, 24, 54, 167, 272, 276, 289, 292, 306, 310
cost of, 18
head regulator of, 208
notch falls on, 224
rainfall small, drainage heavy, 54
Weir at Khanki, 167
head regulator, traveller on, 208
River, 22
Weir, 17
head on, 170
originally too weak, 168
remodelling, 168
settlement of, 169
training works, 167
under-sluices, 172
under-sluice gates, 191
velocity over, 169
Chitpur Lock, plan of, 258
Circular and Eastern Canal, 251, 255, 315
Classes of weirs, 109
Clay, weir built with clay mortar, 109
Co-efficients, Dickens' and Ryves' formulæ, 51
Coleroon River, 101
Weir, 148—149
extremely light, 148
new weir recently built, 148
shutters on, 40 feet wide, 148
Compound dam, 91
Concrete, crushing weight of, 85
weight of in Bhatgarh Dam, 85
Contoured plan required of area to be irrigated, 286
Sidhnai Canal, 287
Contours, display ridges and drainages, 286
Corumbos in Madras, 13
Cost, capital, of irrigation works, 310
of works in operation, 318
of Chenab Canal, 18
of distributaries per mile and per acre irrigable, 297
of drainage and protective works, 300
of Ganges Canal, 19
of head bunds of Ganges Canal, 137
of lifting water, 5
of main canals, 292
of Marikanave project, 80
of new project in the Punjab, 22
of training works at Narora, 160
Counter-balanced shutters on Coleroon Weir, 150
Crest shutters on Chenab Weir, 170
on Jhelum Weir, 173
Crest shutters on Narora Weir, 164
on Okla Weir, 166
on weirs, 111
Crest wall in embankments, 92
Cribs used in Ganges Canal head bunds, 136
Crops, chief, grown in deltaic tracts, 104
irrigated in different provinc
more valuable, irrigated from w
on Punjab inundation canals, 2
on Sind inundation canals, 28
value of, 317
Cross drainage works, Orissa Coast Canal,
Crystalline formation, 6
Cumbam Tank, 7
Currents above a weir, 112
parallel, dangerous to weirs, 112
Cyclonic storms, flow-off from, 54, 55

D.

Dad Canal, 310
Dam. *See also* "Embankment."
Bhatgarh, 9, 82
conditions of construction, 85
compound, 91
Hardwar, 131
Marikanave, 77
conditions of construction, 79
materials used, 80
pressure on per square foot, 79
Mutha, 9
Myapore, Ganges Canal head-works, 134
Niaran Tank, 89
Periyar, 76
Damietta Weir, 174
Dams, dimensions of in Bombay, 95
earthen, 9
maximum pressure imposed, 85
temporary, at head of Ganges Canal, details of construction of, 136
Deccan, development of irrigation in, 320
and Gujarat, cost of canals in, 309
Dedargaon Reservoir, 94, 95
Defects in design of Ganges Canal, 19
Delta Barrage in Egypt, 176
canals in, of Sone River, 19
definition of, 97
formation of, 97
of the Mahanuddee, 97
systems of Madras, 13
Deltaic rivers, decrease in waterway towards the sea, 100
Deltas usually favourable for irrigation, 100
Deposits above weirs, 129
Desert canal, 292, 306, 310
Deterioration of rivers to suit discharge, 99
Development of irrigation in the various provinces, 320
Dhaka Canal, 292, 314
Dhontera Tank Reservoir, 96
Dhunds in Sind, 12
Diagram of floods in Indus and Nile, 27
Dickens' formula for discharge from catchments, 51
Discharge. *See also* "Duty of Water"; "Flow-off."
of Indus, 27
Discharges from large catchments, 51
from rocky and hilly catchments, 58

INDEX.

…r Ganges Canal, 165
…ciples of design of, 204
…tters, 206, 208
…rhind Canal, 156
…one Canals, 204
…hould have raised sill to exclude silt, 208
…rebeni Canal, 210
…dation canals, 25
See also "Weirs."
…Bari Doab Canal, electric notification of floods, 126
too high up the river, 125
…wa Canal, 117
…tern Jumna Canal, 129
…nges Canal, 19, 132
…n rock and boulders, 120
…importance of site of, 107
Jhelum Canal, 173
Kurnool Canal, 115
of Eastern and Western Jumna Canals, 126
position of, 286
Sirhind Canal, 154
…locity… Ganges Canal, 19
…ayas, irrigation in, 1
…gly, silt in, 33
"Horizontals," Egyptian system of regulation, 213
Hurdwar Dam, Ganges Canal head-works, 134
Hydraulic brake shutters of Sone Weir, 186
tables necessary to every canal engineer, 290

I.

Ibrahimiah Canal, silt due to high velocity, 48
Impounded water in canal reaches, 224
Incidence of rainfall, 2
Increase in irrigation in India, 317
Indus, inundation canals from the, 10
maximum discharge of, 27
rise and fall of, 27
the river, 11, 12, 26, 27
Inlets, 228
on Eden Canal, 229
on the Sirhind Canal, 230
Intensity of rainfall, 2
Internal waterways. *See* "Navigation."
Inundation canals, 7, 10, 25
in Bhawalpore, 11
heads of, 25
from the Indus, 16
lift irrigation in, 28
period of flow, 28
principles of design in Egypt, 26
precarious, 12
in the Punjab, dimensions of, 27
silt in, 48
in Sind, 11
in Sind, supplementary supply to, 29
slope of, in India and Egypt, 27
some silt, some do not, 48
Irrigable area by Major Works, 309
Irrigated area in India, 2, 6
restriction of, 289
tracts, drainage of, 299
value of crops on, 318
Irrigation, ancient systems, 6
area of, affected by skill in distribution, 282
Irrigation from bandharas in Kandesh, 116
from canals, 2
Commission, facts concerning areas irrigated, 2
proposals of, 321
dependent on rainfall, 1
development of, 317
efficiency of, dependent on good distributaries, 295
expenditure on, 20
from field to field without channels, 297
great works in alluvial tracts, 6
in India, gross area, 2, 6
by inundation, 6
by mechanical means, cost of, 5
mileage of canals, 20
necessity of drainage connected with, 300
no restrictions in Madras and Orissa, 289
not suited to certain soils, 6
not universal in India, 2
officials, the Patrol, the Ameen, the Zilladar, 305
percentage of rainfall utilised, 20
progress under British Government, 20
restricted to a proportion of commanded area in Upper India, 289
from tanks, 2
from wells, 2, 5
revenue, 302
on various canals, 306
work, the cheapest, the Chenab Canal, 311
the most expensive, the Orissa Canals, 311
works, benefits of, not to be gauged only by financial results, 319
constructed from borrowed funds, 308, 312
far-reaching effects of, 321
in famine years, 319
increased revenue from, 312
two classes for financial purposes, 308

J.

Jaipur, reservoir in, 96
Jamda Canal, 280
Jamrao Canal, 11, 292, 306, 310
Jech Doab, 22
Jhelum Canal, 22, 57, 173, 292, 306, 310
River, 22
Weir, 173
diagonal to the river, 173
under-sluices of, 173
velocity over, 173
Jodhpur, reservoirs in, 96
Jumna Canal, under-sluice shutters, 194
River, 52, 97
Jutoor Weir, 116

K.

Kadva River Canal, 310
Kalegh Sagar Reservoir, 96
Kali Nadi, discharge of, under Nadrai Aqueduct, 237
Aqueduct, heavy flow-off, 57
statistics of, 237
remarkable discharge in, 51
waterway provided, 237
Kanasi Bandhara, 114
Kandesh, weirs in, 9
Kao Syphon, 244

Karez in Baluchistan, 10
Katjori River, 100
Kerai Aqueduct, Midnapore Canal, 240
Khadir lands, 10
Khadva River Works, 292
Khair Reservoir, 89, 96
Khara Spur, construction of, 131
head of Eastern Jumna Canal, 129
trifling cost of, 131
Khareef crops in Punjab, 28
in Sind, 28
season, duty of water in, 272
Khationce, 305
Khusrah, 305
Khyrbanda Tank, 314
Kistna Canal, 15, 20, 306, 310
[illegible], 15, 21, 146
Weir, 146
a bold and successful work, 146
construction of, 147
obstructs half the river, 147
velocity over, 146
Krishna Canal, 280, 310
Kurnool Canal, 116, 291, 310

L.

Lake Fife, 9, 81
Reservoir, 94, 95
working automatic gates of waste weir, 200
Lake Whiting, 81
catchment area of, 82
Lakh Canal, 310
Land revenue, 302
tenure affects success of irrigation works, 320
Lât, the, 3
Leakage from tanks and reservoirs, 63
Leases for irrigation for terms of years, 304
Levels, retrogression of, 112
Lift irrigation on inundation canals, 12
Lock gates, iron, Chitpore Lock, 269
opening gear, 268
valve, Sone Canals, 260
valves, 262, 263, 264, 268
walls, resultant of earth pressures near centre of base, 268
stability of, 259
Lock and fall, arrangement of on Ganges Canal, 256
on Sirhind Canal, 222
general plan in Bengal, 221
Locks on alluvial soil of Bengal, 257, 258, 260
arrangement of lock and fall, 221, 222, 257
built on soft soil without cracking, 261
settlement of Gaowkhally Lock, 259
unequal pressure on foundations cause of cracks, 261
Loss by evaporation and absorption very large, 50
of rainfall in Arabian Sea, 20
Lower Bari Doab Canal, 245, 289
Lower Ganges Canal, 19, 20, 110, 157, 272, 292, 306, 310
area irrigated, 19
escapes in, 44
precarious position of, 159
silting-up borrow pits, 44
training works, 159
under-sluices, 159
Lower Panjhra Canal, 280, 310

M.

Madag Tank, 7
Madaya River, 120
Weir, 121
Madras, cost of canals in, 309
delta systems of, 13
development of irrigation in, 320
tanks, 71
Mahanuddee River, 21, 97
Weir, 140
breach in, 144
centre sluices of, 144
disadvantages of the Frenc 186
foundations partly on sand, partl 144
under-sluices, 144
under-sluice shutters of, 183
speed of working the shutters, 186
Main canals, cost per mile per acre irrigable and foot, 292
dimensions of, 289
Maini Reservoir, 94, 95
Major works, 308, 313
Maladevi Tank, 314
Management of canals, cost of, 306
Mandalay Canal, 120, 239, 292, 310
Weir, 121
Marikanave Dam, conditions of construction, 79
Masonry Dam, 80
project, cost of, 80
Reservoir, flow-off, 69
sluice acting against 80 feet head, 79
Mashvad Tank, flow-off, 61
loss by evaporation and absorption, 61
Masonry, tension on, 244
weight of in several dams, 85
Masonry Dam, 9. *See also* "Dams."
designed in Anmednagar, 250 feet high,
Akhaijitgarh, 89
Alicante, 85
Bau, 85
Bhatgarh, 82
Gileppe, 85
Indian, 76
Marikanave, 80
Mutha, 81
Quaker Bridge, 85
Tansa, 85
Ternay, 85
Villar, 85
Vyrnwy, 85
successful case of very slight design, 89
Matoba Reservoir, 94, 95
Mattresses in Ganges head bunds, 137
Maximum discharge affected by reservoir capacity of river, 52
of Indian rivers, 51
discharges from large catchments, 51
and minimum discharges of rivers in United Provinces, 53
discharge in rocky ground, 58
discharges from small catchments, 53
flow-off a catchment, 50
Mechanical irrigation, cost of, 5
methods of irrigation, 3
Medleri Reservoir, 94, 95

...rhrs on, 96
...on 94, 95
...hoir, 94, 95
...79, 280, 292, 314
...ls, 20, 292, 310
...s, 20
...S, 314
...lt experiments in, 31
...th-west, 1
... Reservoir, 96
...hing weight of, 85
...m, 183, 191
... Reservoir, 94, 95
...ervoir, 94, 95
...nal, 20, 67, 81, 292, 310
loss of water in the, 67
Masonry Dam, 9, 81
...Dam, Ganges Canal, 134

N.

...Nullah Reservoir, 96
...ui Aqueduct. *See* "Kali Nadi Aqueduct."
...raj Weir, 101, 112
...arora Weir, 157
ashlar on crest not successful, 161
blown up, 161
details of, 160
floor lifted bodily, 162
impervious up-stream floor essential, 162
obstructs half the river, 159
pressure experiments, 161
repairs to, 162
Navigable canals, falls on, 224
channels in Egypt free of tolls, 254
waterways, neglect of, in India, 254
Navigation, advantages and disadvantages of combining irrigation and navigation, 253
canals and waterways do not injure railways, 254
generally free of tolls in Europe and America, 254
capital cost of, 252
statistics of, 252
combined with irrigation has not proved successful, 254
extra cost of making irrigation canals navigable, 253
importance of free, 256
internal, in India, 254
on canals designed primarily for irrigation, 252
three large navigable systems, 251
Needle Dam in Jhelum under-sluices, 173
girder, Madaya Weir, 123
weir, Mandalay Canal, 127
Sidhnai Canal, 140
weirs, method of staunching, 140
Needles and horizontals in Egyptian Canals, 213
dimensions of, 173
of steel in Bombay regulators, 213
on regulators in Sind, 213
used for regulation in under-sluices in several weirs 182
Nehr Reservoir, 94, 95
Net profit from Indian irrigation works, 311
New projects in the Punjab, area irrigable, 22
Niaran Reservoir, 96
Nile, in hot weather, completely pumped out, 29
River, 26
subsidiary weirs near Cairo, 174, 176
Nili Canals, 10
Nira Canal, 20, 67, 81, 87, 272, 280, 292, 314
loss of water in the, 67
syphons, 249
Notch falls on Punjab Canal, 224
superior to all others, 227
Notches in canal falls, form of, 227
Nowshera Weir, 37

O.

Occupiers' rate, 303
Off-take of inundation canals in Sind, 25
in Egypt, 26
"Ogee" falls have given trouble, 217
old cannon balls used in, 218
on Ganges Canal, 217
Ojhar Canals, 272
Okla Weir, 157, 175
great width of, 166
narrow under-sluice vents, 166
small under-sluices, 166
velocity over, 166
Oldest canal in the world, 13
Orissa Canals, 15, 19, 20, 47, 292, 306, 310
Coast Canal, 2, 228, 251, 255, 315
Weirs, 141
Outlets at bed of channel, 299
economy, from proper, 299
general rule for, 299
in distributary banks, 298
should be restricted, 299
Owner's Rate, 303

P.

Paschiloorah head-sluice "blown up," 207
Weir, 144
Pandharpur Reservoir, 94, 95
Pangaon Reservoir, 94, 95
Parallel currents, dangerous to weirs, 112
Parsul Reservoir, 94, 95
Pashan Reservoir, 94, 95
Patrol, 304
Penner regulator with "Smart's" shutters, 195
River, 15, 292, 306, 310
Percentage of rainfall utilised, 20
Percolation below Siswan Super-passage, 236
through sand, laws of, 162
Perennial canals, 13
two main classes, 97
system, large expenditure on, 20
Periyar Reservoir system, 73
System, 306, 310
cost of, 76
Persian wheel, 3
Picotta, the, 3
Piers of Sone under-sluices damaged, 154
Pingli Reservoir, 94, 95
Pipe outlets, 298

"Piping" under Chenab Weir, 169
Po, silt in, 33
Pooling below escapes, how prevented, 215
Pressure experiments, Narora Weir, 161
on floors, how determined, 164
maximum in masonry dams, 85
Productive works, 308, 309
Progress of irrigation in India, 20
Projects for perennial canals, 22
for storage reservoirs, 21, 22
Proportion of area irrigated, 2, 6
of *khareef* to *rabi* on Punjab and Sind Canals, 28
Protective works, 309
Public Works Department, 304
Puddle cores in embankments of Kali Nadi Aqueduct, 237
not common in India, 91
Punjab, cost of canals in, 309
development of irrigation in, 320
inundation canals in the, 10, 11
irrigation, new projects, 22
Puttri torrent crosses Ganges Canal, 233

Q.

Quaker Bridge Masonry Dam, 85
Qushesha Escape in Egypt, 216

R.

Rabi crops in Punjab, 28
in Sind, 28
season, duty of water in, 272
Rajputana, evaporation and absorption in tanks, 64
reservoirs in, 88
tanks, 9
Rainfall, abnormal falls very local, 54
average of, in India, 2
does not determine the success or failure of an irrigation work, 319
in short periods important, 54
incidence of, 2
influence on "flow-off," 63
intensity of, 2
minimum for cultivation, 2
on Chenab Canal, 54
percentage utilised in irrigation, 20
proportion which flows off, 50
variation of, effect on irrigation, 1
Ramgarh Reservoir, 96
Rampoor torrent crosses Ganges Canal, 233
Rapid, Cascade, 218
on Bari Doab Canal, 218
Rate, "consolidated," for irrigation, 302
for water, 5
Rates charged for water, 317
low in Bengal, 318
Ravi River, 22, 97
section of at Sidhnai Weir, 138
syphon under, 245
syphon discharges 6,500 cubic feet per second, 24, 247
weir, logs drifting through under-sluices, 216
under-sluice gates, 191
Rechna Doab, 22
Red Hills Tank, 55, 64
Regulation by combination of horizontal and vertical system, 26
Regulation by *kurries* in head-sluices, 41
of inundation canals, induces sil
of supply to Sirhind Canal to pr
Regulator. *See also* "Head Regulator" and
head of Sirhind Canal, 39
shutters, "Smart's" in Madras, 19
Regulators, 202
Chamkour on Sirhind Canal, 213
controlled by needles, 213
in connection with escapes, 213
in Egypt, 213
in Sind Canals, 213
Reinold's automatic waste weir gates, 196
Remodelling Chenal Weir, 168
Delta Barrage, 177
Ganges Canal distributaries, Kennedy's followed, 288
Ganges Canal distributaries, results of, 28
Rents raised by irrigation, 303
Reservoirs, 71. *See also* "Tanks"; "Storage Work
in Ajmere, 96
in Bharatpur, 96
in Bombay, 9
in Jaipur, 96
in Jodhpur, 96
in Mewara, 96
Akhaijitgarh, 89, 96
Ashti, 61, 94, 95
Assuan, 78
Bangalore Waterworks, 65
Baracona, 73
Bareta Bund, 96
Barol, 96
Baroda Waterworks, 62
Bhadalwadi, 94, 95
Bhatgarh, or Lake Whiting, 78, 81, 94, 95
Bhatodi, 94, 95
Bhir, 96
Bitara Tank, 96
Chankapur, 94, 95
Dedargaon, 94, 95
Dhontera Tank, 96
Ekruk, 64, 94, 95
Foy Sagar, 65, 89, 96
Gokak, 94, 95
Kalegh Sagar, 96
Khair, 89, 96
Lake Fife, 81, 94, 95
Lake Whiting, 81
Maini, 94, 95
Marikanave, 62, 77
Mashvad, 61
Matoba, 94, 95
Medleri, 94, 95
Mhasva, 94, 95
Mhasvad, 94, 95
Moran Sagar, 96
Muchkundi, 94, 95
Mukti, 94, 95
Mutha, 81
Nadi Nullah, 96
Nagpur, 65, 58
Nehr, 94, 95
Niaran, 96
Oopahalli, 61
Pandharpur, 94, 95

Syphons, frequently unable to carry the discharge allotted to them, 250
in Egypt destroyed by upward pressure, 244
Kao, 244
liable to be "blown up" by hydraulic pressure, 244
liable to be choked, 244
of steel tubes in concrete, 247
on the Nira Canal, 249
Ravi, 245
steel tube, dangers of, 247
under Ravi River, 24, 245
upward pressure resisted by tie-rods, 244, 245
System of *tatils*, 284

T.

TANKS. *See also* "Reservoirs."
[illegible] and reservoirs, necessity for, 50
[illegible]a irrigated by, 2
[illegible]iti, 9
[illegible]rur, 8
Bombay, 9
capacity of, 9
Chankapur, 314
Chembrambaukam, 7
Cumbam, 7
earliest system in India, 7
evaporation and absorption in, 64
Ekruk, 9, 280, 310
in Bengal, 7, 9
in Madras, 7, 71
33,000 in Madras, 7
on Vedavutty River, 7
Kao Nullah, 7
Khyrbanda, 314
Madag, 7
Maladevi, 314
Mhasvad, 9, 280, 292, 314
Rajputana, 9
Shetphal, 314
surface, 7
Udaipur, 9
Waghad, 9
with masonry dams, 94
with earthen embankments, 94
Tansa Masonry Dam, 85
Tatil tables, 282
Tatils, 282
lead to friction with the people, 282
of distributaries and groups of distributaries, 282
of groups of outlets, 282
of outlets themselves, abolished in Ganges Canal, 282
Temporary dams at head of Ganges Canal, 136
head-works of Ganges Canal, 19
Ternay Masonry Dam, 85
Thapangaing Aqueduct, 239
floods under-estimated, 239
novel falling side walls, 239
Theoretical sections of canals, 290
Thora Nullah Aqueduct, 8
Tidal canal, 310
Toombudra River, 115
Tori Sagar Reservoir, 96
Torrents carried across canals, 230
Torrents crossing Ganges Canal, 233
land raised by, 231
Traffic, water-borne, in Bengal, 255
Training works, 108, 110
at Narora, cost of, 160
Chenab Weir, 167
Lower Ganges Canal, 159
Ravi Weir, 124
Trap formation, 5
Traveller on Chenab head regulator, 208
Treheni Canal, 107, 244, 292, 314
head-sluice, 210
Tree spurs, Lower Ganges Canal, 159
Tungabhadra River, 21
Tunnel valves, 267, 268

U.

UDAIPUR Tank, 9
Under-sluice floor, level of, 180
gates in Egyptian weirs, 194
Narora Weir, 165
peculiar, 165
Ravi Weir, 125
shutters. *See also* "Shutters."
Betwa Weir, 120
Bhatgarh Reservoir, 195
Chenab Weir, 191
double tumbler, 191
Jumna Canal, 194
Mahanuddee Weir, 183
manipulation of, on Mahanuddee Weir, 184
Ravi Weir, 191
Rupar Weir, 191
of Western Jumna Canal Weir, 128
ventage, how determined, 180
vents are now made much wider than formerly, 180
Under-sluices, 107, 108
of Bhatgarh Dam, 86
broad and strong floors essential, 180
Cavour Canal in Italy, regulated by needles, 182
Chenab Weir, 172
effect of, diminished by silt, 111
general considerations affecting, 180
Jhelum Weir, 173
closed by needles, 173
Lower Ganges Canal, 159
Mahanuddee Weir, 144
Mandalay Canal, 121
choked by brushwood, 121
Madaya Weir, regulated by needles, 123
modified by experience, 121
Narora Weir, Lower Ganges Canal, 167
gates not clear of floods, 165
narrow vents in, 164
Okla Weir, Agra Canal, 166
Ravi Weir, 125
regulation by needles not efficient, 123
require long river wing, 180
Rupar Weir, 155
should be closed near head-sluice, 38
small, in Okla Weir, 166
sometimes regulated by baulks, 182
needles, 182

Under-sluices—*continued.*
sometimes inefficient in checking deposits, 111
Sone Weir, 153, 186
ashlar masonry displaced, 161
Western Jumna Canal, 128
Unharwah Canal, 292, 306, 310
United Provinces, cost of canals in, 309
development of irrigation in, 321
map of, 18
Upper Chenab Canal, 22, 289
India, perennial canals of, 17

V.

VALUE of crops, 317
compared with capital cost of canals, 318
Valve, lock gate, Sone Canals, 264
Valves, lock gates, 262, 263, 264, 268
Vedavutty River, tanks in, 7
Velocity of Ganges Canal, high, 19
of new canal in Punjab, 22
in canals, 288
of Sind inundation canals, 12
on crest, Okla Weir, 166
over Chenab Weir, 169
over Jhelum Weir, 173
over Kistna Weir, 146
regulates volume of silt, 3
variation of, causes silt deposits, 49
Ventage of under-sluices, how determined, 180
Verticals, Egyptian system, 213
regulation by, 213
Village channels, alignment of, 287
desirability of, 295
community system in Kandesh, 116
Villar Masonry Dam, 85
Vir, weir at, 120
Vistula, silt in, 33
Vyrnwy Masonry Dam, 85

W.

WAGHAD Tank, 9
(Lesser) Reservoir, 94, 95
Waste Weir, automatic gates of, 87
Bhatgarh, 87
discharging capacity of, 95
dimensions of, 95
gates. *See also* "Automatic Gates."
on Bhatgarh Reservoir, 196
Lake Fife, carries 75,000 cubic feet per second, 198
danger of planked weir, 198
of Lake Whiting, 83
of reservoirs, 195
necessity for automatic gates, 196.
Water, superiority of river to well, 28
Water-borne traffic. *See* "Navigation."
Water rates, 317
compared with value of crops watered, 318
Watershed, canals to follow, 288
Waterway, decrease in deltaic streams, 102
Water-wheels on inundation canals, 12
Weir, afflux due to, 108
at Vir, 120
Betwa, 117
automatic shutters on, 117
Weir crest, ashlar not good, 161
stands well in rubble masonry, 161
Coleroon, 148
constructed by native engineers near Mandalay, 121.
design of, 108
effect on flood levels, 108
Godavery, 147
Jhelum, 173
Kistna, 116
Madaya, 121
Mahanuddee, 140
Narora, 110
of the Chenab Canal, 167
Okla, 157, 166
Okla, obstructs more than half the waterway of river, 166
Rupar, 155
"divide" or river wall, 39
Sidhnai, very light section, 139
Sone, 20, 150
Soonkesala, 116
Western Jumna Canal, 129
Weirs. *See also* "Headworks."
ashlar floors displaced, 161
masonry on crest of, 146
Bandharas in Kandesh, 114
breaches caused by "pound" and friction, 109
"blown up," 110
built by native engineers, 109
built with clay, 109
six main classes of, 109
Chenab, 17
Chilla, on Ganges head-works, 134
constructed by grouting system, 174
crest shutters on, 111
damaged by piping, 110
danger of being out-flanked, 110
of parallel currents, 110, 162
which threatens, 109
deposits above, obstruct navigation, 111
diagonal, 108
Fyzabad, 37
Grand Anicut, 109
in coarse sand, percolation cannot be stopped entirely, 175
in Kandesh, 9
Jutoor, 116
long river wing, 180
materials available determine design, 157
most suitable position for, 108
Narora, 157
Nildhara on Ganges head-works, 134
Nowshera, 37
of the future, 180
on sand, secure under certain conditions, 146
or falls, on canals, 217
Panchkoorah, 144
protection against being "blown up," 170
"piping," 170
selection of site, 108
site determined by available materials, 109
site of, in deltaic tracts, 109
in Orissa, 141
width of base as compared with depth of foundation, 176
Well water inferior to canal water, 28

Wells, area irrigated by, in India, 2
hearted with sand, 170
irrigation from, 5
Western Jumna Canal, 126, 129, 272, 276, 292, 306, 310
head-sluice, 129
weir, 129
Whiting, Lake, 81
Whiting's automatic waste weir gates, 196
Winch, travelling, for under-sluice gates, 192
Wooden shutters, Mahanuddee Weir, 144
Working expenses of canals, 306
irrigation systems, 317

Z.

Zifta Barrage, 178
Zhara Kharez, 10
Zilladar, 305

THE END.

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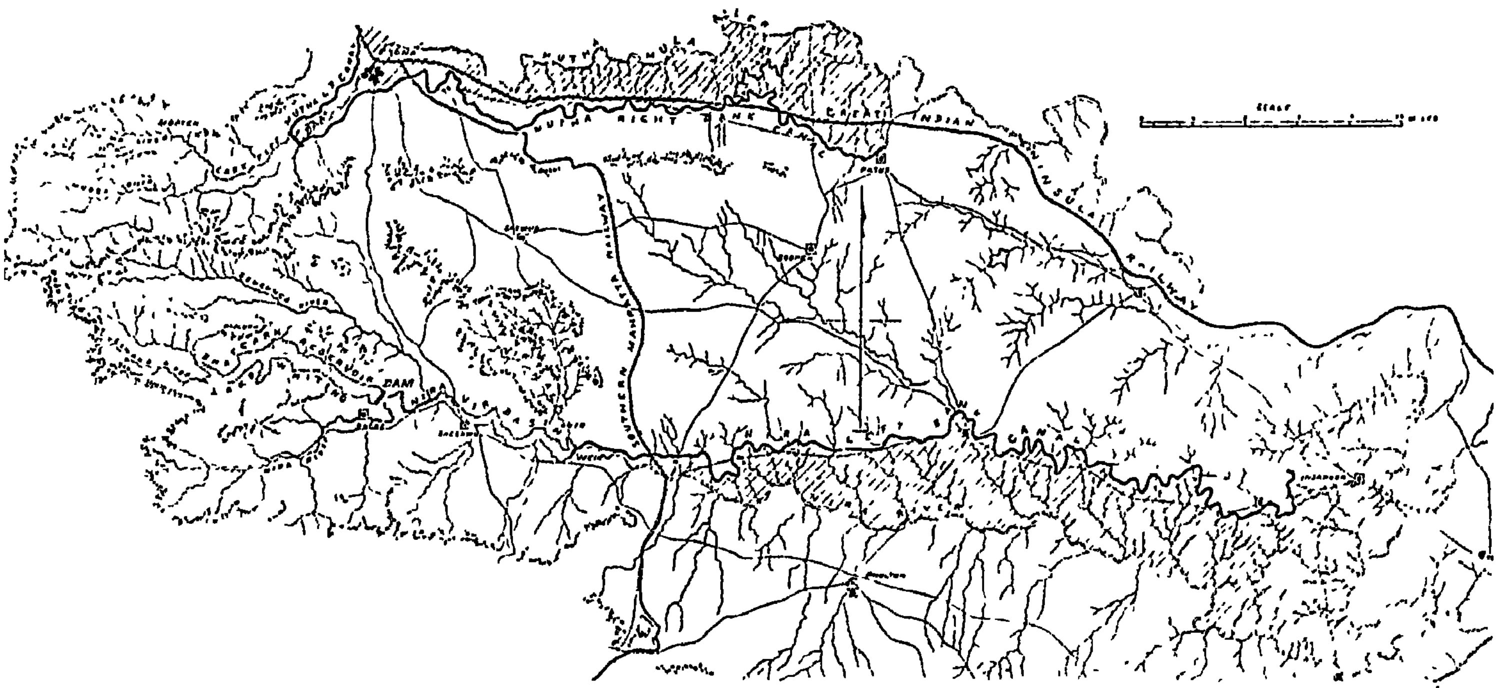
The reservoirs and tanks in the Bombay Presidency are in all cases constructed in hilly ground. They vary in area from 10 square miles of waterspread down to 50 acres, and in capacity from 7,000 millions to 15 millions of cubic feet. The majority of the reservoirs are constructed with earthen embankments, which vary in maximum height from 95 feet down to 29 feet, but there are six which are formed by masonry, or concrete, dams which vary in height from 120 feet to 60 feet. The most important are Lake Fife and Lake Whiting (the Bhatgarh Reservoir) near Poona, which will now be described. The Mutha and Nira rivers[1] in the Poona district of Bombay are fed from the Ghâts, where there is an unfailing rainfall of some 200 inches, and they can always be depended upon to provide an abundant supply of water during the monsoon months, although in the valleys in the eastern portion of the district in which the rivers run, the rainfall is very uncertain, and subject to frequent failure. The necessity of reservoirs in the valleys of these rivers, to store the monsoon supplies, as a protection against



LAKE FIFE AND LAKE WHITING.—NIRA AND MUTHA CANALS

famine, was recognised before Colonel Fife first brought forward, in 1863, the project for the Mutha Reservoir (Lake Fife) and the Mutha Canal which he afterwards carried to completion. This reservoir is formed by a masonry dam of uncoursed rubble nearly 3,700 feet long and 98 feet high, in the loftiest part, above the river bed: the waterspread of the reservoir is about 6 square miles, and it contains nearly 5,000 millions of cubic feet of water, of which rather more than 3,000 millions are available for irrigation.

The main features of the Nira Canal System are:—

I. The Bhatgarh Reservoir, or Lake Whiting as it is now called, on the Yelwandi river.
II. The Vir Basin formed by the weir on the Nira river at Vir.
III. The main canal on the left bank of the Nira river.

The Nira river, during the monsoon months of June to October, discharges much more water than is needed for the full supply of the canal, but, after October, the supply rapidly

[1] This description of the Nira Canal and Bhatgarh Dam is taken largely from the "Report on the Nira Canal Project published by the Government of Bombay in 1892.

Himalayas to the Vindhyas, and extends in a narrow fringe round the coast line of the peninsula. The substrata consist, usually, of alternate layers of sand and clay: the surface shows every variety of soil, from the blown sands of the western deserts to the rich loam of the Ganges valley and of deltas on the eastern coast. The prevailing soil is a yellow or red-brown loam, which yields a largely increased out-turn when irrigated.

The Trap formation covers an area of about 200,000 square miles in the Bombay Presidency, Berar, the Central Provinces, Hyderabad and Central India. When dried by the heat of the sun the soil contracts, in some cases in an extraordinary way, seaming the country with cracks to a depth of several feet. Irrigation is not generally suited to the black cotton soils, but to most others it can be applied freely where the substratum affords good natural drainage.

The Crystalline and Sandstone formation may be said to extend over nearly the whole of the Madras Presidency, also over large portions of Bengal, and of all the other provinces except Bombay. The prevailing soils vary from a dark-red loam in the lower ground to a light sandy soil on the uplands. The better classes of soils in this formation repay the cost of irrigation even more abundantly than the yellow loam of the alluvial tract.

Each of these three great divisions of the soil has its own distinctive features as regards irrigation. The alluvial plains present a surface with so small a declivity that the absorption of a large percentage of the rainfall always occurs. Wells, consequently, in most parts, give a good supply. These plains are traversed by the great rivers, and gentle gradients make it comparatively easy to distribute their waters over the fields. The facilities for this are so pronounced that all the greatest canal systems of India lie in the alluvial tracts.

The area lying in the trap formation is generally marked by broken and uneven surfaces. Irrigation is confined, for the most part, to the more valuable crops; while irrigation works, except of the smallest kind, are rare.

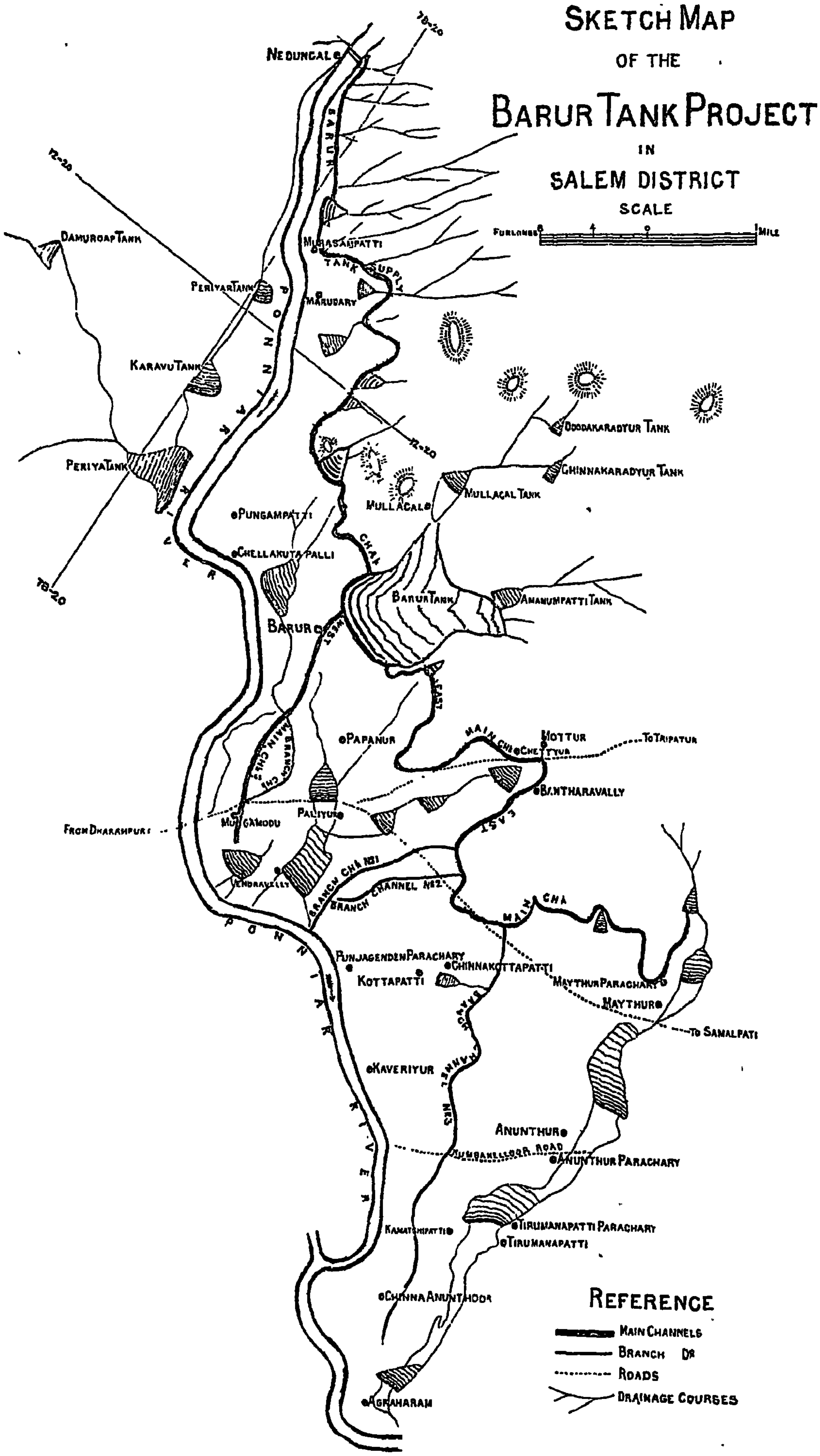
The Crystalline tract is traversed by the large rivers which rise in the western ghauts. The channels of these rivers are generally deep, and their gradients are small. It is, consequently, not easy to utilise their waters beyond the limits of their own narrow valleys; the broken nature of the country increases the difficulty. Beyond the area which is commanded by these rivers in the crystalline tract, there are many tanks which collect the rainfall. The broken and undulating nature of the country gives facilities for their construction; but these works, though numerous, are of comparatively small dimensions, and the distribution of the water is not easy.

In the Alluvial tract 135 million acres are cropped, and 25 per cent. of the cultivated area is irrigated; in the trap formation 58 million acres are cropped, and only 3·2 per cent. are irrigated; in the crystalline formation 100 million acres are cropped, and 15·5 per cent. of the cultivated area is irrigated. The total area irrigated annually in the Indian Empire is about 53 million acres; of this area 44 million acres lie in British India and the rest in native States. About 42 per cent. of the 44 million acres in British territory are irrigated by works which are under the control of the Government, and 58 per cent. are irrigated by works belonging to private persons. More than half of the latter area is irrigated from wells. These can hardly be regarded as irrigation works in the ordinary sense of the term.

The most ancient of all systems of artificial irrigation in the world were probably those which were constructed in the valleys of the Euphrates and the Nile. The natural action of the periodic floods of those rivers produced regular inundations which were controlled to some extent by the people. In India, also, in the valley of the Indus, the regular annual rise of the river produced the same effects. The inhabitants on the banks of the river learnt to excavate small channels through the higher lands on the immediate brink of the stream, to irrigate lands

which were not naturally flooded by the river. They thus commenced the system of inundation canals which, for unknown ages, have tapped the rising waters of the Indus and have irrigated the fertile lands lying in the comparatively rainless plains of its valley. These alluvial plains have the physical characteristics which are common to the riparian lands of many Indian rivers, and which are apparent in all deltas. The annual overflow of the floods has raised the lands gradually, and has raised those in the vicinity of the river more than those lying at a distance from it, because the silt in the waters has been primarily deposited near the bank of the river where the velocity of the stream is first checked. By this action the country has a slope both on the line of the axis of the river and in the direction at right angles to it. This is a condition most favourable to irrigation, and the early constructors of inundation canals soon learnt to take advantage of it.

One of the earliest systems of irrigation in India was by surface tanks. They are found to some extent in all parts of India, and are common in the Shahabad district of Bengal, but are to be counted by thousands in Madras, where millions of acres of rice crops are irrigated from them. These tanks vary in size from a few acres to 9 or 10 square miles of water surface. They are usually formed by earthen embankments thrown across small local drainages, often of only 2 or 3 square miles in area, or by a series of such embankments thrown across the valleys leading from larger catchments: thus, in Shahabad, in Bengal, the Kao Nullah, having a catchment of 54 square miles and a maximum discharge estimated at 9,000 cubic feet a second in flood, was crossed by a series of earthen embankments, which, completely blocking the course of the stream, formed a series of tanks, or *ahrahs* as they are locally called, of which the largest had a bank about 20 feet high and a water surface of four or five square miles. The floods were impounded in this series of tanks and utilised subsequently for irrigation, the surplus from one tank flowing by earthen escape channels to the one below. In years of very heavy rainfall these local tanks were occasionally breached, and the supply stored was lost, and in years of deficient rainfall many failed to fill at all. In Mysore, on the Vedavutty river and its confluents, there is a somewhat similar chain system of tanks, except that they are mostly in torrents or rivers with much greater slope than the drainages of Bengal. In Bengal but few of these old tanks were provided with any masonry works for draining off the water or for regulating the discharge, but in Madras, where there are some 33,000 tanks, the majority are provided with masonry works. The Madras tanks also depend mainly on local rainfall, but they are sometimes fed from rivers or streams by means of channels taking off above weirs constructed in the beds of the rivers. There are about 550 weirs across rivers or streams in Madras, each connected with a series of tanks, or with a single one. The dependence on local rainfall renders the irrigation from these tanks to a certain extent precarious, but the area ordinarily irrigated from works of this kind in Madras exceeds 3½ million acres. In some cases the embankments, which with one or two exceptions are all made of earth, are built in gorges; thus the embankment of the Cumbam tank in the district of Kurnool, which is between 80 and 90 feet high, is little more than 100 yards long, but the water surface of the reservoir is about 8 square miles; while another example, the Chembrambaukam tank, about 14 miles from Madras, has an embankment 3 miles long which sustains a maximum depth of only 22 to 23 feet; it has a water-spread of about 10 square miles and a capacity of 116 millions of cubic yards. There are remains of other works of even greater size, such as the Madag tank in the Dharwar district of Bombay, which have failed or been abandoned. The inscriptions on two large tanks in the Chingleput district of Madras, which still irrigate from 2,000 to 4,000 acres, are said to be more than 1,100 years old. In Upper Burma


SKETCH MAP
OF THE
BARUR TANK PROJECT
IN
SALEM DISTRICT
SCALE
FURLONGS 8 4 0 1 MILE
NEDUNGAL
BARUR
MURASAMPATTI
TANK SUPPLY
MARUDARY
DAMUROAP TANK
PERIYAR TANK
KARAVU TANK
PERIYA TANK
PONNIAR RIVER
DODDAKARADYUR TANK
CHINNAKARADYUR TANK
MULLACAL TANK
MULLACAL
PUNGAMPATTI
CHELLAKUTA PALLI
BARUR TANK
AMANUMPATTI TANK
BARUR
WEST
EAST
MAIN CHL
BRANCH CHL
PAPANUR
MOTTUR
CHETTYUR
TO TRIPATUR
BANTHARAVALLY
FROM DHARAMPURI
MUNGAMODU
PALIYUR
VENDRAVELLY
BRANCH CHL NO1
BRANCH CHANNEL NO2
MAIN CHL
PONNIAR RIVER
PUNJAGENDEN PARACHARY
KOTTAPATTI
CHINNAKOTTAPATTI
MAYTHUR PARACHARY
MAYTHUR
TO SAMALPATI
BRANCH CHANNEL NO3
KAVERIYUR
ANUNTHUR
KUMBANELLOOR ROAD
ANUNTHUR PARACHARY
KAMATCHIPATTI
TIRUMANAPATTI PARACHARY
TIRUMANAPATTI
CHINNA ANUNTHOOR
AGRAHARAM
78-20
12-20
REFERENCE
MAIN CHANNELS
BRANCH DO
ROADS
DRAINAGE COURSES

there are many tanks, constructed centuries ago, of which that at Meiktila is the most important. The celebrated tank at Udaipur, in Rajputana, which is said to be the largest in India, is not utilised for irrigation; but there are many old tanks in Rajputana and Central India which are so used, although the majority have been abandoned or are useless. Nearly two-thirds of the irrigation in the Gujarat, Deccan, and Carnatic districts of Bombay depend on small storage works, and there are 50,000 small private tanks in the Central Provinces which irrigate 650,000 acres in years of high demand. Tank irrigation is to be found in some form or another in all provinces of India, except the Punjab and Sind, where it is unknown, or nearly so. In Mysore the Nuggar tank has an earthen embankment 84 feet high and 1,000 feet long, and a tank is formed on the tributary of the river Lokain by a bank only 225 feet long, but 117 feet high. In Bengal surface tanks, in almost all cases, depend on their local catchment, but in Madras tanks are often grouped together and fed from rivers. The Plate on the opposite page shows one of these systems in the Salem district, which has been greatly improved by Government since 1883 by the construction of a weir across the river Ponniar, and of a system of supply channels and sluices. In British India some 8 million acres are annually irrigated from tanks. A very large proportion of this area is watered by works originally constructed under native rule and by native engineers. The maintenance of many of these tanks is now undertaken by the British Government, and that Government has constructed several large storage works, which, however, only irrigate a comparatively small proportion of the total irrigated by works of this class.

In Rajputana, in the districts of Ajmere and Merwara, 387 tanks are maintained by Government. They are mostly formed by earthen embankments. In the native State of Jaipur, in Rajputana, about 200 small irrigation works, costing some 60 lakhs of rupees, have been constructed during the last thirty years, and they have proved a financial success. The works have cost Rs. 124 per acre on the average.

In the Bombay Presidency there are few rivers with a perennial supply, and the general scantiness of the rainfall, which is practically confined to the monsoon months, has necessitated the construction of tanks in connection with nearly all works of irrigation. The slope of the country is usually steep and the depth of soil is small; the rainfall, consequently, passes off rapidly, and the shallow soil does not maintain moisture for the growth of any but the most scanty crops. The rivers, with few exceptions, have a very small flow except in the monsoon; reservoirs are consequently essential if the surplus water of that season is to be conserved for use in the dry months. There are between thirty and forty tanks maintained by Government, varying in size from a few acres up to 10 square miles of water-spread[1]; most of these have earthen embankments varying in height from 30 to as much as 114 feet, but there are five or six with masonry dams, of which the most noticeable are the Mutha Dam (Lake Fife), which has a maximum height of 98 feet, and the Bhatgarh Dam (Nira Canal), with a maximum height of 127 feet. The principal reservoirs with earthen dams are the Ekruk, Mhasvad and Ashti tanks, with storages of 3,330, 3,072 and 1,550 million cubic feet respectively. These have dams 76, 80 and 58 feet high. The highest earthen dam in Bombay is that of the Waghad tank, which is designed to be 95 feet high, but is not yet fully completed. [2]Small native canal systems are to be found in the Khandesh and Nasik districts, in the centre of the Bombay Presidency. These consist of low masonry weirs built

[1] A list of these tanks, with statistics, is given in the "Irrigation Manual" by Col. J. Mullins, R.E. (E. & F. N. Spon), and particulars of many of them in "Indian Storage Reservoirs," by W. L. Strange (E. & F. N. Spon). See also pages 94 to 96 of this book.

[2] Note by Mr. W. L. Strange of the Bombay P.W.D.

across rivers with a perennial flow, from which canals are led to compact irrigated areas known as *thalls*. The canals are carried along the river banks until they gain command, and are furnished with regulators, escapes and cross drainage works. The heads are peculiarly liable to damage by the heavy floods which occur in the rivers. The Government carries out the larger repairs to the weirs and canals, but petty repairs are left in the hands of the irrigators, who use the water very economically. This class of irrigation does not increase in Bombay.

In Baluchistan, where the rainfall is scanty and very capricious, irrigation has been effected, from time immemorial, by a system not dissimilar to that of the *fontanili* in Italy. The country around Quetta, and the town itself, is alive with small streams of water which are derived from tunnels driven into the hill-sides, which tap underground springs. Each of these tunnels is called a *karez*, and is generally only just large enough to permit a man to creep through it. The natives construct these *karezes* by sinking shafts from the surface about 50 to 80 feet apart, on the line which they intend the *karez* to follow, and then connecting the bottom of the shafts by a tunnel: the spoil is lifted up the shafts by baskets. In most cases there is no timbering or lining of any kind to the tunnel, and the result is that the *karezes* frequently fall in, and become choked. The Zhara Karez has a tunnel which is driven about 5,000 feet into the hill-side with a slope of 3 feet in 1,000; the water is led from the mouth of the tunnel by an open channel to the fields, or to a tank where any surplus water may be stored until it is required. This *karez* is about 3 feet high by 20 inches broad, and it gives a discharge of about 9 cubic feet a second. The natives of the district are very clever in discovering likely places for these little irrigation works.

The practice of leading water from rivers and streams to irrigate adjacent lands was probably practised even before the time when the construction of tanks was undertaken. The most primitive system was that of making comparatively shallow cuts through the river bank into which the water flowed when the level of the river was raised by the regular floods which occur annually in most tropical streams. The canals made on this system are called in India *Inundation* canals, and in Egypt, where the system has found the fullest development, they are known by the name of *Nili*. The chief inundation canals of India are found in the basin of the Indus and of its five tributaries. It will be seen from the Irrigation and Rainfall Map (page 6) that the six[1] rivers of the Punjab, when they issue from the Himalayas, come upon a narrow belt at the foot of the mountains where the supply of rain varies from 40 inches downwards. About 100 miles from the hills they enter the arid region of Western India, in which the rainfall varies from 10 inches to even as little as 2 inches in the year. In the course of ages the rivers have cut into the soil and have left high land on either side of the valley, some 4 to 10 miles wide, in which each river follows a more or less tortuous channel. The river has, in the course of many centuries, varied its position throughout the valley, leaving steep scarps on either side at the boundaries of its wanderings. The higher land on each bank, which is from 10 to 50 feet above the general level of these valleys, is called the *bhangar*, the lower land the *khadir*. The *bhangar* lands form the *doabs*, as they are called, lying between the six rivers; they are fertile in themselves, but cultivation depends entirely on the scanty rain, or, if artificial irrigation is not provided, on laborious irrigation by mechanical means from wells which are often 60 and 70 feet in depth. The *khadir* lands are naturally fertile, but the *bhangar* lands, though formed of good soil, are to a considerable extent covered with grass or brushwood, or entirely waste. As the rivers converge into the single stream

[1] The description of the inundation canals is largely taken from "East India Progress and Condition, 1872—3." Printed 2nd June, 1874, for the House of Commons.

of the Indus, near Mithankot, the *bhangar* lands gradually disappear and the low *khadir* extends right across between the rivers. Some of the inundation canals of the Punjab lie in the *khadir* of the higher reaches of the Sutlej and the Jhelum, but the majority of them, as shown in the Plate (page 6), are in the area bordering on the confluence of the rivers with the Indus. The district of Multan, lying between the Sutlej and the Chenab, where rain hardly ever falls, is rendered beautifully fertile by a series of inundation canals, taken from both rivers, which are said to have been originally constructed by the Afghan rulers left by Aurunzib. In the Derajat, on the right bank of the Indus, above Mithankot, there is a group of twelve inundation canals which have been constructed since the British rule, and in Muzuffarghar a corresponding group irrigates a tract some 12 miles broad on the left bank. The Upper Sutlej inundation canals are in the central portion of the *doab* lying between the Sutlej and the Ravi rivers. Here the face of the country is covered with traces of former life and prosperity. The cause of decay was due to the loss of water-supply consequent on the diversion of the river Bias, which formerly had an independent course to the Chenab, fertilising the land on either bank; but in 1790 it was diverted into the Sutlej, and its old bed became a dry ravine with a complicated system of deserted watercourses. A new system of inundation canals has been carried into this tract from the Sutlej. The inundation canals of the Punjab aggregate some 2,500 miles in length, and irrigate more than one million acres.

Lower down the course of the Indus, in the almost rainless tracts of Sind, and in the native State of Bhawalpore, the flood waters of the river are diverted by inundation canals on to the thirsty ground. The canals of Sind aggregate some 6,000 miles in length, and irrigate 1½ to 2 million acres of crops, which could not be grown at all without them. Sind is an alluvial plain, almost every portion of which has been swept by the Indus at some time or another. Traces of ancient channels are to be met with in every direction. The river has gradually worked its way from east to west. In 710 A.D. the invading Muslims found a Hindu dynasty at Alor, and the ruin of Alor was caused by the river moving to the west; the seat of government was then moved to the city of Brahmanabad, the ruins of which are now 45 miles from the river. The river, more or less continually, carries away its banks in one direction and forms new land in another: from Sukker to the sea, a distance of 300 miles, the banks are permanent at only three places, Sukker, Jhirk, and Kotri. At Sukker the river rushes through a narrow gorge in the limestone rocks, forming a rapid when the river is in flood. At Jhirk the river is not contracted, but there is rock on either side. At Kotri the hills approach on both sides, and the clay soil is deep and tenacious. Some of the largest canals in Sind were at first natural channels, others have been dug by various rulers of the country. They resemble natural water-courses in many respects, but they have been greatly improved since the British occupation. Before that time all the canals were simple inundation ones having open mouths from the river, but many of them have since been provided with regulators. The Jamrao canal, the only canal in Sind which is entirely artificial, was completed in 1900: it draws its supply above a weir, constructed across the Eastern Nara, a larger overflow channel which branches off the Indus in the northern part of Sind. It has a full supply discharge of about 3,000 cubic feet a second. The largest of the Sind inundation canals is the Fuleli; orginally it was a natural branch of the Indus, which it rejoined about 16 miles below Hyderabad, but the outlet into the river was closed by a dam in the time of the Amirs, and the water was sent forward to feed other canals to the south. The improvement of the Fuleli by the British was commenced in 1856, when two new supply channels were cut from the Indus with very satisfactory results on the supply. There are several other inundation canals in Sind of large size, such as the Begari,

the Eastern Nara, and the Baghar, which have maximum discharges of from 4,000 to 7,000 cubic feet per second.[1] The depth of some of these canals is as much as 15 feet: the velocities vary from 1 to 3 feet per second. The latter velocity is sufficient to prevent silt deposits without causing erosion. The full supply level of the canals is generally kept below ground level, to prevent breaches, but as near ground level as practicable. Owing to the slight slope of the country and the small amount of rainfall there are very few cross drainage works. The principal masonry works are regulators, bridges, and outlets, which are built of vitrified brick to resist the effect of the salts, chiefly carbonates, sulphates, and nitrates of magnesia, soda and potash, which are washed from the ground. The rainfall is to a certain extent collected in depressions, known as *dhunds*, which occur all over the country. Those inundation canals which have a small velocity silt badly and have to be cleaned annually. Without its canals Sind would have a very small cultivated area, but, by means of them, some 3 million acres are annually irrigated: the systematic development of the canals by Government is steadily increasing the area.

Inundation canals give, at best, a precarious system of irrigation; if the floods of the rivers, from which the canals are drawn, are regular, and the duration of the flood is sufficient, the cultivation is secure, provided that the canals have been cleared of the silt deposits of the previous year; but when the floods are low, or only remain for a short time at their full height, it is impossible to pass the necessary volume of water on to the fields, or even to give any water at all to many of them.

The Indus[2] begins to rise in April and May in consequence of the melting of the Himalayan snows, and continues to rise until about the middle of August, when it falls pretty rapidly until the beginning of October: after that the fall is more gradual. The water begins to flow into the Indus inundation canals in sufficient volume to allow the ground to be softened for ploughing when the river has risen to 12 feet on the gauge at Bukkur or 15 feet on the gauge at Kotri; these heights are usually attained in the month of June, and, according as they are reached or not by the end of that month, a fair forecast can be made of the probabilities of the inundation. When the cultivators see June pass by without these heights being reached they become discouraged, and curtail their preparations for cultivation in anticipation of a deficient supply of water. The 18th of June may be taken as a fair average of the latest date on which the river should rise to give a good prospect of successful cultivation, and if a further rise of 2 feet does not take place before the middle of July, the area of land which can be ploughed becomes restricted; for all land must be softened with water before it can be ploughed, and if the river has not risen sufficiently to irrigate the lands by flow, the cattle, which should be ploughing, have to be employed in lifting water by water-wheels to moisten the land. A considerable number of these wheels is employed in connection with these inundation canals, partly because the level of the water in the canals is entirely dependent on that of the river, consequently land which may be commanded at one stage of the river cannot be irrigated by flow at another, and partly because the original alignment of many of the canals of the Indus is in the low ground and does not give a command of the country.

The area of cultivation dependent on inundation canals maintained by Government in the Punjab and Sind, in the valley of the Indus and its tributaries, is about 4 million acres; but in addition to the Government canals there are minor ones belonging to private owners in the Punjab, and there is an extensive system in the native State of Bhawalpur, which extends for 300 miles along the left banks of the Sutlej, Chenab, and Indus. So that the gross area dependent on this system of irrigation is considerably in excess of 4 million acres.

[1] Paper by Mr. W. L. Strange, of the Bombay P.W.D.

[2] Revenue Report of Sind.

A very large proportion of the area now under irrigation in India is commanded by perennial canals taken from the large rivers. It is impossible to draw any very distinct line between inundation and perennial canals. There are some canals which are perennial in the sense that water does flow in them all the year round and yet the discharge is so small during the dry season of the year, as compared with that of the flood season, that they would more properly be classed with inundation canals, although that term is usually only applied to channels with an intermittent discharge. The extra depth to which such canals are cut may be sufficient to take in the water when the river is at its lowest, but the real object of it often is to increase the discharge in the season of inundation. A perennial canal may be only an inundation canal cut to a sufficient depth, but usually it has head-works in or across the river from which it is taken. One of the oldest canals[1] in the world, if, indeed, it is not actually the oldest now in operation, is the Bahr Yusuf in Upper Egypt. Tradition relates that the canal was constructed by the patriarch Joseph (Yusuf) in the days of the Captivity. It was originally an inundation canal, but, after various alterations and improvements, it is now perennial.

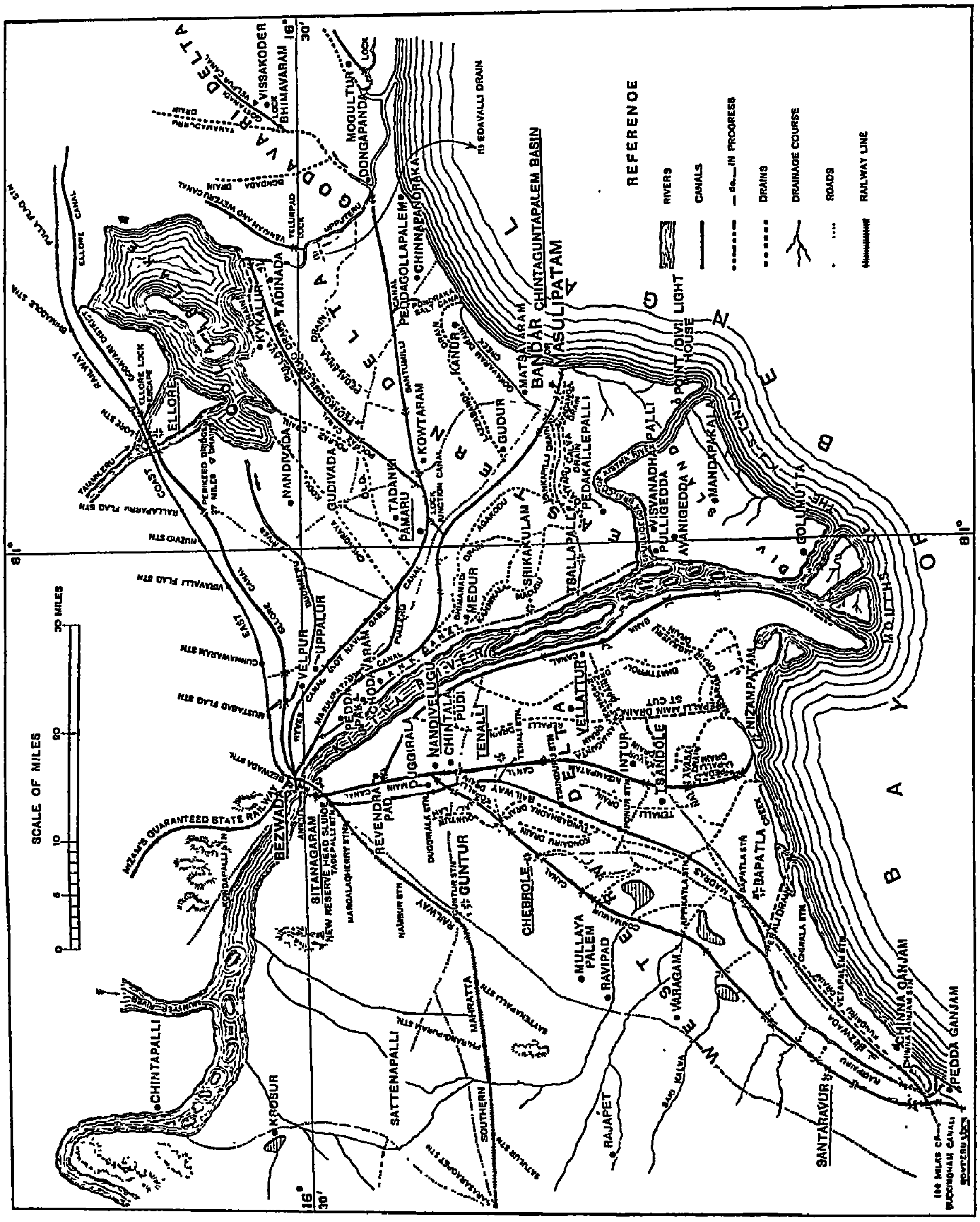
The construction of perennial canals in India was probably first instituted in Madras, where, as has already been stated, there are numerous examples of channels leading a constant supply of water from streams. Most of the weirs on the Tungabhadra channels, for instance, were constructed by the Hindu monarch, Krishna Raya, at the beginning of the sixteenth century. In some cases, and notably in the case of the channels emanating from the Grand Anicut, as it is called, in the Tanjore district, these canals drew their supply from permanent weirs or *anicuts*, but in many cases a dam or *corumbo* was constructed across the river every year as the flood fell, to retain the water at a sufficient height to compel it to flow into the canals. These *corumbos* were often made of sand and brushwood only, and completely closed the channel of the river, diverting the entire supply into the canal.[2] The Grand Anicut is said to have been constructed sixteen hundred years ago, and the Madras native engineers certainly carried out works of this kind long before anything of the sort was attempted in other parts of India. The earliest canals, in Upper India, of which any records exist are the old canals taking off from both banks of the Jumna. The one on the west bank in the Punjab is attributed[3] to Firuz Shah, who, about the middle of the fourteenth century, is said to have cut a canal to irrigate his favourite hunting grounds near Hissar. The canal seems to have fallen into disrepair, but in the sixteenth century Akbar ordered its restoration; and again, early in the seventeenth century the Emperor Shah Jehan carried the canal by aqueducts and deep rock cuttings into Delhi. The Eastern Jumna Canal, on the other bank, was originally commenced by Shah Jehan about the same time as he undertook the extension of the canal on the other bank to Delhi. When the English came into possession of the country these old works were in ruins, but their restoration and improvement were very soon taken in hand. One of the earliest systems which was projected by the British after the annexation of the Punjab was the Bari Doab Canal lying in the *doab* between the Ravi and Bias rivers. There had in this case also been a small canal in the district prior to the British occupation, which was also one of Shah Jehan's works undertaken in the early part of the seventeenth century.

The earliest examples of successful perennial canals are to be found in the delta systems of Madras. The great range of hills known as the "Western Ghâts," which runs parallel to the Arabian Sea, near the west coast, for a distance of about 1,000 miles, forms a great

[1] But see page 139 of "The Unseen Foundations of Society," by the Duke of Argyll, concerning canals excavated by Khammorati, who reigned in Babylon before the days of Moses.

[2] "Professional Papers of Madras Engineers," vol. i. p. 80.

[3] "East India (Progress and Condition), 1872—73," printed for the House of Commons in 1874, p. 60.

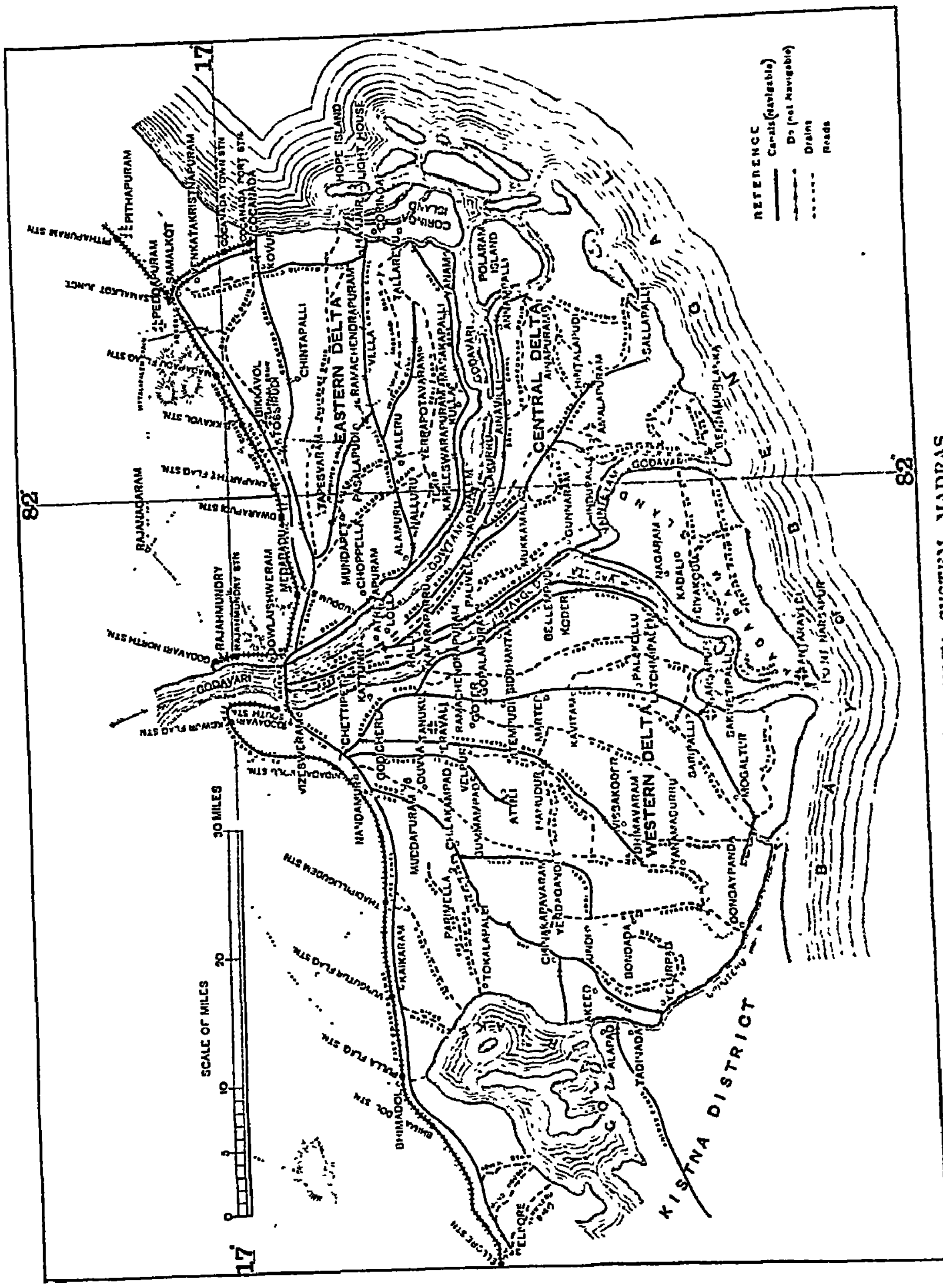


KISTNA DELTA SYSTEM, MADRAS.

watershed, which throws all the rainfall of the country lying to the east of it into the Bay of Bengal. An area of about 340,000 square miles is drained chiefly by four great rivers—the Godavery, Kistna, Penner, and Cauvery—into that sea. This area includes parts of the Bombay Presidency, the whole of the territory of the Nizam of Hyderabad, part of the Central Provinces and Berar, and almost the whole of the Madras Presidency. The deltas of the rivers at their confluence with the ocean were poverty-stricken, sparsely cultivated tracts, subject to recurring droughts, but the irrigation systems which have been constructed in them have converted them into highly cultivated and prosperous areas. The Cauvery[1] or Coleroon system is the most ancient, both as regards the original works constructed by the natives, and with reference to the improvements of them by the British Government which were commenced in 1836 under the supervision of Colonel (Sir Arthur) Cotton. The area of irrigation dependent on this ancient system, before any improvements were effected in it by the British Government, was 669,000 acres; now it is about one million acres. About 25 lakhs of rupees only have been spent on the improvements. This irrigation system is the largest delta system, and it is the most profitable of all the works in India. There are six or seven somewhat similar delta systems in Madras, and one in the delta of the Mahanuddee in Orissa, in Bengal (Plate opposite page 16). The Kistna[2] system is perhaps the most interesting. The delta of the Kistna is divided by the river into two almost equal parts: the Eastern Delta is 1,160 square miles in area; it extends from the left bank of the Kistna to the confines of the delta of the Godavery, the navigable canals of the two systems being in communication at these places. The Western Delta has an area of 960 square miles. In 1792 a Major Beatson invited the Government of Madras to consider the idea of utilising the waters of the Kistna for the irrigation of its delta, but nothing was done, until in 1832—33 a famine devastated a great part of the Madras Presidency, and many thousands perished in the Kistna delta because their crops had failed from drought. This gave new life to the old scheme of Major Beatson; the Government, however, arrived at the conclusion that "very large and costly works like an *anicut* at Baizwarah are clearly inexpedient and impracticable under existing circumstances." This condemnation of the project held good until the successful operations of Colonel (Sir Arthur) Cotton proved its fallacy, and, in 1852, after many reports and consultations, the Bezwada Anicut was commenced. It was completed in 1855. The weir is 3,714 feet long and 20 feet high above the deep bed of the river. It was constructed on a deep bed of pure sand in a gorge where the floods rise, on occasions, as much as 40 feet. The flood discharge over it has reached 770,000 cubic feet per second, which gave a depth of between 18 and 19 feet over the crest. A series of canals, as shown on the plan on the opposite page, take off from either bank of the river; they aggregate some 370 miles in length, and irrigate 550,000 acres of land. The total cost of the system was only 135 lakhs of rupees. It has always paid most handsomely and been of immense benefit to the country it commands.

The Godavery system, which is illustrated on the following page, was constructed by Sir Arthur Cotton before the Kistna system was commenced. At the head of the delta of the Godavery the deep bed of the river is only some 8 or 10 feet below the highest parts of the delta, so that it was easy to command the whole area. A weir was constructed across the river at Dowlaishwaram, where the total width from bank to bank is 3½ miles. but where four islands reduced the actual length of weir to about 2¼ miles. The works were sanctioned in 1844. The river at the head of the delta bifurcates into two streams, which divide the area under command into three sections, each of which is watered by a canal taking off the river above the

[1] "East India (Progress and Condition), 1872—73," printed for the House of Commons in 1874, p. 69.
[2] "The Engineering Works of the Kestna Delta," by George T. Walch, Madras, 1899.



GODAVERY DELTA SYSTEM, MADRAS.

anicut (or weir) across the river. In the eastern section the main canal soon bifurcates, one branch following the high bank of the river, and the other flowing along the foot of the hilly ground bordering the delta at this part: both these branches throw off many other channels to irrigate the lower land lying between them. In the same way the canal in the central section of the delta throws off branches along the high bank of the river, which command the country between them, while one of them, in its lower reaches, crosses a branch of the river in an aqueduct of forty-nine arches. In the western section, the main canal divides into several branches, one of which, as in the eastern section, follows the margin of the delta, and the other follows the river bank. The main lines of canal in this system are constructed for navigation as well as for the supply of water. The area irrigated in 1901—1902 exceeded 830,000 acres.

The perennial canals of Upper India are all, with the exception of the Eastern and Western Jumna Canals, comparatively modern works constructed by the British Government. In the Gujranwala district of the Punjab, however, there are traces of many old canals which have fallen into disuse many years ago. The Kilri Canal, 50 miles in length, which used to feed a reservoir near the town of Sheikhupura, is one of the chief of these old works. The Bari Doab Canal was the first of the modern works in the Punjab: it was commenced, in 1850, partly as a measure to give employment to the large number of Sikh soldiers who had lost their means of livelihood by the annexation of the province. The headworks of the canal are on the Ravi near Madhopore, where the river emerges from the hills, and where it has a minimum discharge of 1,200 cubic feet a second, which can be diverted by the weir across the river into the canal. The maximum discharge of the canal has exceeded 4,500 cubic feet per second, and the area irrigated is nearly 900,000 acres. The nature of the *doabs* of the Punjab rivers has already been explained (page 10); in this case the main canal is carried down the centre of the high land, and numerous branches are thrown off which command the greater part of the upper portion of the tract lying between the Ravi and the Bias. The system consists of 369 miles of main and branch canals, and nearly 1,200 miles of distributaries. The Sirhind Canal is one of the most important of the large perennial systems; it emanates from the Sutlej near Roopur, in the Umballa district of the Punjab, at the point where the river issues from the Siwalik Hills, and irrigates portions of the British districts of Loodiana and Ferozepore, and of the native States of Puttiala, Sheend, and Nabha. There is a masonry weir across the river, and a regulating sluice at the head of the canal, which takes off the left bank of the river: the minimum discharge of the river is said to be 2,800 cubic feet a second; the maximum discharge of the canal is 6,000 cubic feet. The construction of the works was commenced in 1869, and they were first brought into operation in 1882; the area irrigated in 1899—1900 was 930,000 acres in British territory, and 440,000 acres in native territory.

The Chenab Canal is one of the most modern of the great perennial systems. It lies between the Ravi and Chenab rivers in the Punjab. It is the largest of all the Indian systems; and, from more than one point of view, it is the most interesting. It was originally opened as an inundation canal which was only in flow in the flood season. It was soon proved that unless a weir was constructed across the Chenab river, from which the canal draws its supply, it would not be possible to prevent the canal being choked with silt. A weir was, consequently, built across the river with a waterway of 4,000 lineal feet, divided by piers, 10 feet wide, into eight lengths of about 500 feet each. On the crest of each length there are hinged iron shutters, 6 feet high and 3 feet wide, which can be dropped, when the river rises, by a let-go gear worked from the piers. The shutters, when the floods subside, are raised either by hand or by a crane travelling on the floor of the weir below the shutters. The canal takes off the river immediately above the weir. It has a base of 250 feet and a maximum depth of nearly 11 feet: the

discharge recorded in it has been as much as 10,800 cubic feet per second. The tract which it commands, known as the Rechna Doab, is nearly all Crown land. Before the construction of the canal it was almost entirely waste with an extremely small population, which was mostly nomad. Some portion of the country was wooded with jungle trees: some was covered with small scrub camel thorn, and large tracts were absolutely bare, producing only, on occasions, a brilliant mirage of unbounded sheets of fictitious water. Such was the country into which 400 miles of main canals and 1,200 miles of distributaries now distribute the waters of the Chenab; turning some two million acres of wilderness into sheets of luxuriant crops. The main canals and the branches run on the ridges of the country, and the major distributaries are on the minor watersheds: some of these distributaries carry as much as 500 cubic feet a second. When the canal came into operation villages had to be formed in the previously uninhabited tracts, and settlers had to be introduced. Each settler, on being installed, was practically guaranteed water for a certain proportion of his holding, and, in order to ensure this, the lands were elaborately demarcated and the levels of the whole area were most carefully taken. All the Crown lands were divided into squares of about 1,100 feet side, and boundary pillars were erected with a systematic series of numbers. These numbered land-marks were designed, originally, only for revenue purposes, but they were soon found to have another use. The engineers, at first, not unfrequently went astray on the vast trackless wastes of the Rechna Doab, or missed their way in the jungles. The boundary pillars, with their systematic numbers, were a clue by which they were able to find the direction of their camps. About 1,500,000 acres of the Crown lands have now been allotted to colonists, and a new population of a million people have founded homesteads which they cultivate with the waters of the Chenab Canal. A telegraph line extends over the whole system, mainly for water regulation, and a railway runs through the heart of the irrigated tract. There is one feature of this irrigation system which is novel. The canals are so aligned that it is not possible to escape surplus water back into the river: there is, consequently, a difficulty in disposing of any surplus volume flowing in the channels. Those who are conversant with the regulation of water in a large canal system will appreciate the anxiety of an engineer, who knows that a canal above him is bringing down over 10,000 cubic feet a second, and that he must, some way or another, arrange to dispose of it. On the Chenab Canal seven depressions in the ground have been selected and surrounded with earthen banks: these form reservoirs into which it is possible to divert surplus waters on an emergency. The Chenab Canal has cost about £2,000,000; it commands 2,645,000 acres of culturable land and has actually irrigated, in one year, nearly two million acres.

The Jhelum Canal, in the Punjab, commands an area of one and a half million acres in the Jech Doab, which is an arid waste lying between the Chenab and Jhelum rivers. The canal carries nearly 4,000 cubic feet per second. It is the most recent of the great Punjab systems, and was brought into operation in an extraordinarily short time. In January, 1899, the staff began to collect, and preliminary operations were commenced; in October, 1899,[1] the actual construction of the headworks was put in hand; in May, 1900, the head regulator, under-sluices and one quarter of the weir were completed, and the whole of the weir was finished in May, 1901. The river, which had during the construction of the works, flowed round the right flank of the weir, was diverted over the weir by December, 1901. Irrigation on a small scale was actually commenced in the *kharecf* season of 1901, that is, only eighteen months after the first brick of the headworks was laid. The entire project, which is estimated to cost Rs.1,81,89,849, will irrigate 787,418 acres, which 51·4 per cent. of the gross area commanded. In 1903—1904 the area actually irrigated was 279,260. In addition to the three perennial systems which

[1] "The Jhelum Canal Headworks" of Mr. H. J. Johnston, Punjab, Technical Paper No. 133.

have been described there are five or six others of smaller magnitude in the Province of the Punjab.[1]

In the North-Western Provinces, or United Provinces as they are now called, the Ganges and Lower Ganges Canals are the two principal perennial systems (Plate opposite page 18); both of these take off the right bank of the Ganges, the Lower Ganges Canal by means of a weir built across the bed of the river, and the Ganges Canal by the help of temporary embankments of rubble-stone, fascines, and earth, which are annually made after the subsidence of the floods, and annually destroyed when the floods rise.[2] In the tract commanded by the Ganges Canal cultivation was, formerly, almost entirely dependent on wells, but near the village of Rampore there is said to have been an old canal from the West Kali Nuddi about 12½ miles in length, which is supposed to have been constructed by Muhummud Aboo Khan to irrigate groves and gardens in the neighbourhood of Meerut. Traces of this canal still exist. The Ganges Canal consists of 440 miles of main and branch canals and 2,700 miles of distributaries, and the Lower Ganges Canal has 558 miles of canals and 2,400 miles of distributaries. The area actually irrigated by the former has exceeded 1,250,000 acres in a famine year, and by the latter 1,000,000 acres. The Ganges Canal was commenced in 1848, and was opened in 1854. The Lower Ganges Canal[3] was commenced in 1872, and was opened in 1878.

When the full supply for which the Ganges Canal was designed, 6,750 cubic feet per second, was admitted for the first time into the canal, certain defects in the design became apparent; the chief of these was an excessive slope in the bed of the main channel. The effects of this were enhanced by the open "ogee"[4] falls with crests on the level of the bed which had been constructed. The high velocity of flow which was induced caused considerable erosion of the bed and of the sides of the canal, as well as dangerous scour immediately below the falls. At that time but little was known about the flow of water in large earthen channels and in computing the slope, Dubuat's formula, which is now known to be quite unreliable, especially for large canals, had been used.

It was found, however, that an expenditure of about nine lakhs of rupees was sufficient to remedy the original defects in the project. Protective works were added to the fourteen great masonry falls; their crests were raised to reduce the slope of the canal; additional weirs were built with the same object and also to facilitate regulation of supply; and some minor alterations were made. In all other respects the main features of the work remain to this day substantially unchanged. It has long been universally admitted that Sir Proby Cautley exercised sound judgment and wonderful foresight in the alignment and general design of the canal. Without any previous experience of irrigation works, on anything like the same scale to guide him, he designed and constructed a canal system which is still one of the largest in the world in a way in which the light of subsequent experience has disclosed but few faults. The cost of the canal has been about 30,000,000 rupees. The Ganges Canal renders very valuable assistance to two other important works, as it supplies a large proportion of the water in the Lower Ganges Canal, and, on certain occasions, materially supplements the discharge of the Agra Canal.

In the province of Bengal there are three perennial irrigation systems fed from rivers. The Orissa Canals have already been mentioned as being of the same class as the Madras Delta Canals. The Sone Canals in Behar (Plate opposite page 24) are similar to the perennial canals of Northern India in some respects, and, at the same time, they have many features in common with the delta systems; indeed, the area commanded by the Sone Canals may be regarded as

[1] See statement on page 310.
[2] See page 136.
[3] Note by Mr. Hutton.
[4] See page 217.

the delta of the Sone river at its junction with the Ganges, in the same way that the Madras and Orissa systems command the deltas of the various rivers at their junction with the Bay of Bengal. The Sone Canals were commenced in 1869, and came into operation in 1874. A weir 2½ miles long, in one continuous piece of masonry, spans the river at Dehree. A main canal is taken off on each bank of the river, and each of these is divided into branches as the necessity of the ground requires. The minimum discharge of the river is about 300 to 400 cubic feet a second in the hot weather, and in the floods a volume of 830,000 cubic feet a second occasionally passes over the weir. The maximum discharge of the canals is 6,000 cubic feet per second. The largest area which has as yet been irrigated in one year has been 555,000 acres. The system consists of some 370 miles of main and branch canals, and, 1,200 miles of distributaries. The Midnapore Canal is another perennial system in Bengal, which irrigates about 80,000 acres of land, cultivated almost exclusively with rice crops.

The British Government, during the last sixty years, has devoted the greater part of its expenditure on irrigation works to the perennial systems which draw their supply from the great rivers. In the 'forties the delta works of the Godaveri and the Cauvery were inaugurated and extended. In the 'fifties the Bari Doab Canal in the Punjab, the Ganges Canal in the North West, and the Kishna Delta system in Madras came into operation. In the 'sixties four canal systems in Bombay and two in Bengal were added. In the 'seventies the Sone Canals in Bengal, the Lower Ganges and Agra Canals in the North-West, the Mutha and Nira systems in Bombay, began to collect irrigation revenue. In the 'eighties the Sirhind Canal was in effective flow, and in the 'nineties the Chenab Canal commenced its notable career of usefulness. In the middle of the last century Government irrigation works watered only 3 or 4 million acres; twenty-five years later the area had increased to about 10 million; and now it is about 20 million acres. Three-fourths of this area is irrigated by canals entirely constructed by the British Government from borrowed funds, and the rest by old canals, maintained, improved and extended by the State. During the last half century India has expended about 30 millions of capital on these works, which have an aggregate mileage of some 44,000 miles of canals and distributaries. The investment is a good one from a purely commercial point of view, as the net profit amounts to about 6 or 7 per cent. on the outlay.

But although it is true that great progress has been made in the last half century, it is a fact that only a small percentage[1] of the supply of water in India has been utilised for the benefit of man. It is a fact, also, which those who are not acquainted with the circumstances fail often to appreciate, that it is not possible to utilise more than a comparatively small proportion of the gross water supply. It has been estimated that the water evaporated from the ground, together with that which sustains plant life and is absorbed in the soil, amounts to 59 per cent. of the gross rainfall; that 35 per cent. is discharged by the rivers into the sea; and that only the remaining 6 per cent. is utilised in irrigation. This is, of course, only an estimate based on probabilities; but, whatever the figures may be, the volume used in irrigation is, at best, a small percentage of the rainfall. It is commonly thought that a large proportion of the 35 per cent. which is, in some sense, wasted, might either be directly diverted on to the land or stored in reservoirs for future use. It has already been stated that although there are great variations in the incidence of the rainfall, the total annual fall is not subject to marked fluctuations, and it is suggested that arrangements ought to be made to divert the surplus of one tract to supply the deficiencies of another. For instance, nearly 16 per cent. of the whole surface flow of India is directly lost every year in the Arabian Sea from the steep slopes of the

[1] Indian Irrigation Commission, 1901—1903.

Western Ghâts. There is one work which, by a bold design, taps the flow on the western side of the hills, and, by means of a tunnel through them, diverts the water on to the eastern table-lands. But the opportunities for such works are not numerous, and the cost is high. In Northern India, again, there is vast storage provided by Nature in the snows and glaciers of the Himalayas; yet the Irrigation Commission of 1903 reported that only 6 per cent. of the available water supply is utilised for irrigation. In this part of India the conditions affecting irrigation are exceptionally favourable, and large extensions of canals are still possible. But if all the works, which are now conceived to be feasible, were constructed in the Punjab and Sind, 60 per cent. of the surface flow of water must still escape to the sea.

The matter of the possible storage of the surplus water, in years of plentiful rainfall, to provide irrigation in years of drought, is one which presents many attractions. Investigations have, however, shown that, in the vast majority of cases, it is not possible, at any reasonable cost, to provide the amount of storage required. It is often forgotten that, in the alluvial plains, the area required for storage might be nearly as great as that which might be benefited by the utilisation of the impounded water; the land slope is small, and the losses due to natural causes would be great. Again, as such irrigation is not always necessary, and as it is impossible to predict a year of drought, the reservoirs would have to be filled every year although for several years the water might not be required. On the other hand, in the Western Ghâts, where water could be stored to irrigate tracts which often need it badly, dams of great height would be generally essential; the broken nature of the ground would necessitate tortuous and expensive channels: cyclonic storms produce floods which demand heavy escapes; and the construction of reservoirs would, in many cases, involve the destruction of valuable village sites and the submergence of much fertile land. These facts give some foundation for the opinion that, although a large extension of irrigation works is yet feasible in India, it is not possible that more than a small percentage of the water which now flows into the sea will ever be used in maturing crops on the land.

Sites have been examined on several of the rivers which flow into the Bay of Bengal with the view of constructing reservoirs in the valleys. In such rivers as the Tungabhadra,[1] the Kistna, the Cauvery or the Mahanuddee, for instance, it would probably be possible to construct masonry dams which would form lakes holding 30,000 millions of cubic feet, and even much more in some cases. During the monsoons of the most unfavourable years the unutilised supplies of these rivers would fill such reservoirs many times over. In the case of the Cauvery river there are records, extending over a quarter of a century, which show that the surplus discharge, not required for existing navigation works, varies from 72,000 to 670,000 millions of cubic feet. The minimum would suffice to fill a reservoir twice the size of the great reservoir on the Nile at Assuan. But the conditions are less favourable than in that case. During five months in the year, when the waters in the Indian rivers are clear and free from silt, the supplies in them are, in several cases, barely sufficient to supply existing irrigation works, and it would not be possible to impound water at that time. During the monsoon months, when there are vast supplies available, the water nearly always carries large volumes of silt in suspension. The deposit of this in the reservoirs would seriously threaten the life of them, and would, besides, deprive the water of the fertilising matter which is so greatly valued by the cultivators. It would no doubt be possible, in some cases, to adopt the plan, which has been followed at the Bhatgarh and Assuan reservoirs, of allowing the muddy waters to pass through sluices in the dams and to impound only the clearer water. But this would not always be possible. In the case of the Cauvery, for instance, the records show that a full reservoir could not be relied

[1] Note by Sir Thomas Higham, K.C.I.E., St. Louis Exhibition, 1904.

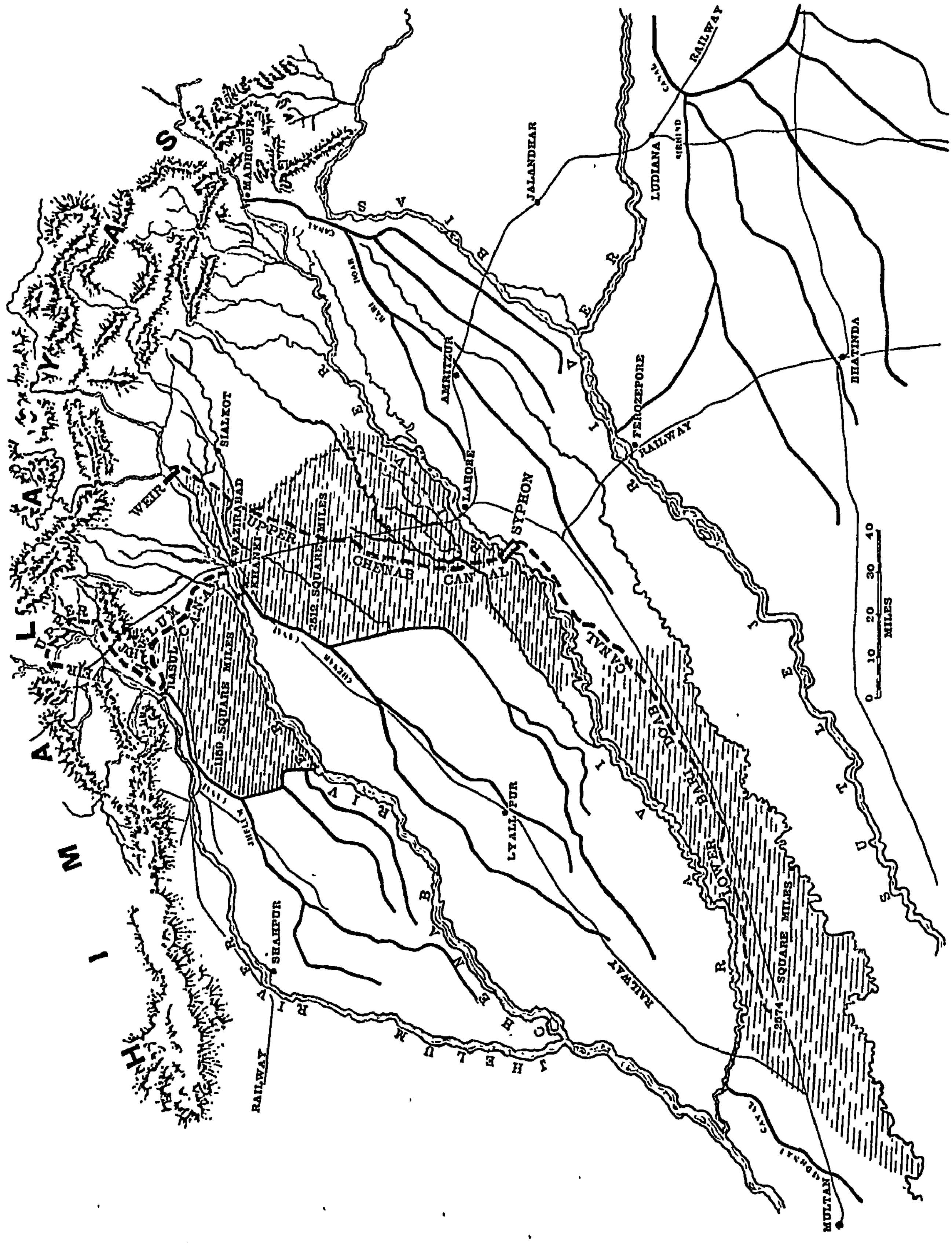
on, if impounding were to commence later than the 15th of July. There is no month, after July, in which the surplus is not liable to fail absolutely, and there is, also, no month in which high silt-bearing floods are not likely to occur. In the case of reservoirs which have been proposed on the Tungabhadra and Kistna the conditions are more favourable, but still there would be much danger of heavy silt deposits in them. These considerations tend to make Indian engineers pause before recommending large reservoir schemes on the great Indian rivers, but further investigation and study may demonstrate the advisability of some of these great projects.

But although great storage works are required for any considerable extension of irrigation in the tracts which are most exposed to famine, much still remains to be done in the construction of perennial canals from the snow-fed rivers of the Punjab. The vast Sind-Sagar Doab will some day be irrigated from the Indus. Above the Jhelum and Chenab Canals and below the Bari Doab Canal there are large tracts of land to which irrigation can be most advantageously applied, and the Secretary of State has recently sanctioned three new canals to be constructed to irrigate them at a cost of Rs. 78,238,925—say, £5,300,000. The three canals are intimately connected with each other, and really form one great scheme. They will irrigate 1,876,000 acres of land from 230 miles of main canals, 274 miles of branch canals, and 2,714 miles of distributaries. It is estimated that the gross revenue will be 96 lakhs of rupees—£640,000—and the net revenue 78 lakhs—£520,000—which is nearly 10 per cent. on the capital outlay. The canals are not designed for navigation purposes, but for irrigation only. The largest of the three canals will carry nearly 12,000 cubic feet per second, which is greater than the discharge of any existing canal in India. It will be a channel about 270 feet broad and 11 feet deep, flowing with a velocity of nearly 4½ feet a second.

The three canals which make up this great project[1] are the Upper Jhelum Canal, the Upper Chenab canal, and the Lower Bari Doab Canal (Plate on opposite page); they will irrigate three totally separate tracts which stand greatly in need of water. These tracts are known as the Upper Jech Doab, the Upper Rechna Doab, and the Lower Bari Doab. The Upper Jech Doab lies between the Jhelum and Chenab rivers, close to the Himalayas; it is a tract of fertile land, largely dependent for its water supply on rainfall and on the occasional flow of torrents proceeding from the neighbouring ranges of hills. The southern portions of this tract have been subject to famine. The Rechna Doab lies between the Chenab and the Ravi rivers; it has a fairly high spring level, and, consequently, a considerable extent of well irrigation. The riverain tract, on the south-east of it, is subject to droughts, and irrigation is much needed. The Lower Bari Doab is a great tract of high land of good quality, now largely covered with jungle, and used mainly as a grazing ground for camels. There is no doubt that when it is irrigated nearly a million acres of land, which are now mostly waste and sparsely populated, will be covered with fruitful fields and teeming villages.

The irrigation of the first tract, the Upper Jech Doab, is to be effected by the Upper Jhelum Canal, which will draw its supply from the Jhelum river. This river has a discharge which rarely falls below 6,000 cubic feet per second, and in good years it has a minimum of about 10,000 cubic feet in the cold season. There is already one canal which draws its supply from this river, but, after setting aside sufficient to supply that canal, it is estimated that from 6,000 to 8,000 cubic feet per second can, in most years, be taken from the river in the cold-weather season. A portion of this supply will be used in irrigating the Upper Jech Doab, but a large volume will be passed forward through the canal into the Chenab river, which flows to the east of the Jhelum. The function, therefore, of the first of the three canals is largely to act as a

[1] Report by Mr. Benton on the Project for Canal Extension in the Punjab.



SANCTIONED PROJECT FOR NEW CANALS IN THE PUNJAB.

duct to lead the surplus waters of the Jhelum river into the Chenab. This latter river is already tapped by the great Chenab Canal, one of the most prosperous and beneficial of the Punjab irrigation works, and there is little or no water to spare in it to irrigate the Upper Rechna Doab; so the necessary volume—or a large portion of it—is to be taken from the Jhelum. But the configuration of the ground is such that it is not possible to take the Jhelum water at a sufficiently high level to command the Rechna Doab, so the water drawn from the Jhelum will be poured into the Chenab a little above the head of the existing Chenab Canal, and the supply necessary for the Upper Rechna Doab will be drawn off the Chenab river at a point some forty miles above. With this water the thirsty land of the Upper Rechna Doab will be irrigated.

The third tract, the Lower Bari Doab, lies to the east of the Ravi river, in the Montgomery district. It should naturally draw its supply from its own river, the Ravi. But the supply of that river has already been hypothecated. The old Bari Doab Canal, which was opened in 1859, and which irrigates all the upper portion of the *doab* lying between the Ravi and the Sutlej, has absorbed most of the available supply. So the Punjab engineers are going to adopt a bold course; they will construct a great syphon under the Ravi river and take a portion of the supply of the second canal—the Upper Chenab Canal—right under that river into the waste lands of the Lower Bari Doab. This syphon will be no small work. It will carry a discharge of 6,500 cubic feet per second under a river having a flood discharge of about 200,000 cubic feet a second. The syphon will be about a quarter of a mile in length, and the top of it will be 4 feet below the spring level of the country.

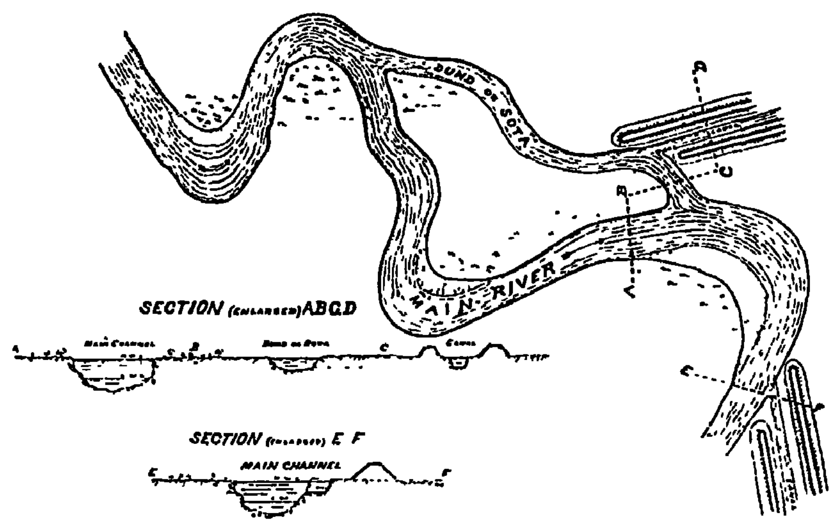
This great project, then, really relies on the water of the Jhelum for its supply. The first tract, commanded by the first canal, lying to the east of the first river, will be directly watered from the Jhelum; the second tract, commanded by the second canal, lying to the east of the second river, will be irrigated by water drawn actually from the Chenab but stolen, so to speak, from the Jhelum; the third tract, commanded by the third canal, lying to the east of the third river, will be irrigated by water from the same source after it has dived below the Ravi in order to reach the tract which, of all the three, most needs its refreshing influence.

CHAPTER II.

INUNDATION CANALS.

Heads of Inundation Canals—Colonel Tremenheere's Experience on the Indus—Rise and Fall of Indus Flood—Lift Irrigation on Inundation Canals—Superiority of River Water to that of Wells—Crops grown in the Punjab and Sind—Inundation Canals in Egypt.

THE heads of inundation canals are generally situated on the true bank of the main river from which they draw their supply. In nearly all Indian rivers, especially in those parts of them where inundation canals exist, there are depressions or hollows taking off from the main stream, which are dry, or nearly so, during the dry season, but are filled by the annual flood in the river: these are generally old courses of the parent stream which have been abandoned by the river; they are called *dunds* in Sind and *sotas* in Bengal. These depressions are frequently used in Sind as the sites for the heads of inundation canals: one of the arguments used in their favour is that, as they are much larger than the canals they feed, the velocity of the water is less in the *dund* than in the canal channel, and, consequently, the silt, which would otherwise be deposited in the canal, is deposited in the *dund*, and the labour of the annual silt clearances of the canal is reduced. This is undoubtedly the case with reference to the coarser sand which is carried along the bed of the river by the force of the current: the fact that the bed of the *dund* is above that of the river prevents the inflow of this material into the *dund* to a considerable extent, and the reduced velocity in the *dund* itself checks the onward flow of that which may enter, so that a still smaller quantity reaches the canal.



OFF-TAKE OF INUNDATION CANALS.

The above sketch shows a case of this kind: the inundation canal at C D is drawn off the *dund* at a level slightly above the bed of the *dund*, which is considerably above the bed of the main river. In the sketch the *dund* is open at its lower end, but not infrequently an embankment may be made at some point such as B C, and the entire discharge of the *dund* forced into the canal. In that case the silting of the channel would be greatly increased, and the length above B C would silt up more rapidly. When the lower end of the *dund* is open the amount of deposit would be much less, but it is then doubtful whether the amount of silt in the canal at C D would be greatly less than in the case of the canal at E F, which is drawn directly from the main channel of the river, provided that the level of the bed was the same, and that the bank of the river above the canal head was a stable one. A canal taken off on a cutting bank or immediately below a cutting bank is soon choked with silt. These remarks apply

mainly to rivers such as the Indus and the Nile, which carry a preponderance of earthy matters in suspension in the waters. But where a river carries a large proportion of sand in suspension, and which has, therefore, a higher velocity than one which carries finer matter, an advantageous way of constructing a canal, with the view of excluding the heavier sandy silt, would be that shown by the canal at C D: a masonry escape might be constructed at B C and a head regulator built to the canal, say at the line C D, through which the supply should be regulated so as to draw the water as far as possible from the surface of the stream. This can be done by combining the system (see page 213) of horizontal and vertical regulating baulks, the lower portions of each vent in the regulator being closed by horizontal baulks and the supply regulated above them by verticals.

The native rulers, who originally constructed most of the inundation canals in India, appear to have learnt from experience the necessity of selecting spots for the heads of the canals which were screened from the full force of the current during the inundation. The experiments made by Colonel Tremenheere, R.E.,[1] show that—

(1) Those inundation canals of Sind, which draw their supply from branches separated from the main river by islands covered with brushwood and long grass, contain a comparatively small amount of material in suspension. The brushwood and grass impede the velocity of the water and clarify it.

(2) That canals having their heads in the main stream where the velocity is normal may be expected to contain silt to the extent of $\frac{1}{300}$ by weight, and that about one-third of this quantity is ordinarily deposited in the canals.

(3) That canals having their heads on the main stream in a part where the channel is restricted and the velocity increased may contain silt to the extent of $\frac{1}{200}$ by weight, of which half may be deposited in the canal.

These points have always to be considered in selecting a site for the head of an inundation canal, and they explain why a favourite site is a little way above the point where the lower end of a *dund* joins the main stream, for if, as is often the case, the *dund* ultimately silts up at the head, a backwater is formed at the lower end, from which water can be drawn which is comparatively free from the heavier silt. But such a head would only be a temporary one, as a rule, for the backwater would sooner or later become filled up by deposit.

The inundation canals of Egypt are now being reduced in importance owing to the construction of the Assuan dam and the conversion of large areas in Upper Egypt from the old "basin" system of irrigation to that of perennial supply. The Egyptian inundation canals are only partly used for the irrigation of standing crops: their main function has been to fill the "basins" during the flood with the fertile Nile water, but their origin and system of working is substantially the same as that of the Indian canals of the same class.

Colonel Justin Ross, who was Inspector-General of Irrigation in Egypt, found that the old inundation canals of the Nile were usually[2] aligned by the Arab engineers on the following principles:—

(1) The off-take should be placed in the bank along which the deep water of the Nile flowed, and the canal axis should be, as nearly as possible, a tangent to the general curved sweep of the central current of the reach of the river in which the canal lay. The natives altered the heads of some canals, at great expense, in order to fulfil this condition.

[1] "Roorkee Professional Papers," 1st series, vol. iii. page 25.

[2] "Notes on the Distribution of Water and the Maintenance of Works in Upper Egypt," by Lieut.-Colonel Justin C. Ross, C.M.G., page xxiii. Cairo, 1892.

channels, one being kept closed during the height of the flood, and opened when the first has silted so much as to diminish the supply below the requirements. The canals are generally very tortuous, and were aligned more with reference to the requirements of individuals or villages than with reference to the best manner of irrigating with economy.

The inundation canals of the Punjab commence to fill with water about the end of April or beginning of May, and run dry about the end of September. During the earlier months, before the flood has risen sufficiently, lift irrigation is practised. The superiority of the river water over that of wells is demonstrated by the fact that near the heads of the Punjab canals the cultivators prefer to pay canal rates and to lift the water from the canals rather than to lift it from wells, although the canal level and the spring level are about the same. When the flood has risen sufficiently, the autumn or *khareef* crops of rice, bajra, jowar, cotton, indigo, &c., are irrigated by flow, and, at the same time, considerable areas of fallow land are flooded, with the double object of manuring the land by the silt deposit, and of saturating it so that sufficient moisture may be retained in the soil to mature the *rabi* crop. This crop consists mainly of wheat: it is grown after the rivers have fallen too low to command the fields. In this respect the irrigation from these inundation canals is similar to the "basin" system of Egypt, but it is not conducted on nearly so large a scale, nor so methodically and efficiently. In the Punjab the crops which are grown, mainly by flow irrigation, during the time of the inundation (*khareef* crops), are greater than those (*rabi* crops) which are grown after the subsidence of the rivers on fields which have been moistened during the inundation, in the proportion of about 5 to 4. It not unusually occurs that the inundation of the *rabi* lands is not sufficient to entirely mature the crop, and that the fields are watered to some extent from wells after the inundation canals have ceased to run.

In Sind, the crops, grown mainly by direct flow from the inundation canals, during the period of the inundation, bear a far larger proportion to the entire irrigation than is the case in the Punjab, the area under these crops being about seven times as large as that under the cold weather (*rabi*) crops. The crops in Sind are chiefly jowar, bajra, and rice, the area under these three crops alone being nearly nine-tenths of the total extent of the irrigation (about 3,000,000 acres). In Sind the proportion of land irrigated by lift is much greater than in the Punjab, the canals being generally in lower ground and more in soil. The Sind inundation canals are larger than those in the Punjab; there are seven or eight which carry between 1,000 and 4,000 cubic feet a second on the average, and one, the Fuleli Canal, which averages nearly 8,000 feet in ordinary years.

The opinion has been expressed[1] that the inundation canals of Sind are already being prejudiced, to some extent, by the construction, in the Punjab, of the large perennial systems which draw their supply from the tributaries of the Indus. The inundation canals, as a rule, take their supply from the Indus when it is in flood, but there are a certain number of them which are really perennial and draw from the Indus, for *rabi* irrigation, in the cold season. In that season the discharge of the Indus is comparatively small. In March, 1903, the discharge at Sukkur was only 18,947 cubic feet per second and at Kotri it was 19,772 cubic feet. The average daily discharge of the Indus at Sukkur for the three months January, February, and March, 1903, was less than 30,000 cubic feet per second. The great works[2] constructed of late years in the Punjab draw off as much as 15,000 cubic feet a second from the five tributaries, and this deduction from the supply of the Indus cannot be ignored. It may affect the existing irrigation in Sind to a small extent at present, but the time may come when Sind will make

[1] Para. 31, Part II. of Indian Irrigation Commission's Report, 1902—1903.
[2] Ibid., para. 93.

weirs across the river and have her own great perennial systems, and then the draught of the Punjab canals will be very appreciably felt. In the hot weather in Egypt every drop of the water in the Nile is drawn off or pumped out of the river, and embankments are actually made at the mouths of the river to exclude the sea water. The same thing may yet occur on the Indus. It is a question which will have to be decided how far it is right that the *doabs* of the Punjab should absorb the supply which might be led on to the plains of Sind.

Mr. Thomas Summers, who has much experience in Sind canals, has suggested a means of supplementing the supply of the inundation canals at the end of the season, when water is of great value. He proposes to impound water, when the river level is high, at or near the mouths of the canals, and to discharge it into them gradually when the quick drop in the river occurs in September. There are several cases in which this could be done by forming storage reservoirs between the double lines of river embankments, or by constructing cross bunds between canals which run close together. The water would be stored for a few weeks only, and would often be of great value.

CHAPTER III.

SILT.

Nature of Silt—Proportion of Silt in different Rivers—Quantity of Material carried to the Sea by the Indus and the Nile—Silt in Suspension—Analysis of Silt—Shingle Deposits in the Ganges and Jumna Canals—Heavy Silt Deposits in Sone Canals—Sand carried into the Canal by Flow along the Bed—Silt in the Sone and Sirhind Canals—Flushing out Silt in Canals of Upper India—Canals choked by Drifting Sand—Surface Draught preventing Silt—Flushing Canals—Scouring Silt—Kennedy's Method—Silt in Baree Doab Canal—Brick and Stone Groynes to prevent Silt—Silting Checked by Uniform Velocity.

THE silt which is borne in suspension in the waters of rivers consists of organic and mineral matters, which, while they are often a source of abundant advantage to the fields, are, not infrequently, the cause of much trouble in the channels of irrigation works. It is desirable in all cases to pass forward to the fields as much fertilising material as possible, but it is also desirable to prevent the deposition of the silt in the channels, where it impedes, and sometimes completely chokes, the discharge.

Silt varies enormously in its nature, according, generally speaking, to the velocity of the river which carries it and to the character of the catchment area of the river. Thus, in the canals taking off the Ravi, the Jumna, and the Ganges, near the points where these streams first debouch from the hills, and where the fall of the beds is from 10 to 19 feet in a mile, and the velocities are as great as from 10 to 15 feet a second, the matters which are occasionally swept down to impede and sometimes to block the channels consist mainly of shingle and boulders. Lower down the courses of these same rivers and other similar ones, shingle and boulders give place to coarse sand mixed also with mud, carried by velocities of perhaps 5 to 8 feet a second, at surface slopes of 1 to 2 feet a mile: and nearer the sea, where, as in the case of the Nile in Egypt or the Ganges in Bengal, the surface slope of the floods is from 5 inches to as little as 3 inches a mile, the silt consists of the finest sand mixed with a large proportion of mud, borne by a stream flowing with a velocity of only 2 or 3 feet a second. This silt when deposited is a soft slimy mud of a highly fertilising nature.

Unfortunately very imperfect records exist of the amount of silt carried in suspension by rivers. There is no doubt that the volume of silt carried by any particular river varies very greatly according to the conditions of the moment. In the dry season an Indian river may flow with almost absolutely clear water; while at the top, or near the top, of a high flood in the rainy season the proportion by weight of solid matter to liquid may be as great as 1 to 30 or even less. In tidal rivers in Eastern Bengal the volume of silt at the same place, on the same day, may be ten times as great at one period of the tide as it is at another. In one river the amount of silt may depend—generally does depend—largely on the volocity of the stream in the river itself, while in another it may be more largely influenced by the character of its tributaries. The volume of silt varies, unquestionably, with the depth of the water in most cases, and, probably, with the distance from the bank of the stream. It will almost certainly be different on the convex and concave banks of a bend. All these circumstances make it difficult to assign a true value to any given experiment: bare facts may be misleading. However, such facts may be of some value.

The experiments of Messrs. Humfreys and Abbot on the Mississippi show that the amount of silt increases slightly according to the depth from the surface of the river: the silt at the bottom being about 6 per cent. greater than at the surface in the case of that particular river, which is one of the moderate velocity of 4 feet a second or less.[1] In rivers of greater velocity it is probable that the difference may be greater, but this is a point on which little evidence has been recorded.

The following table gives some evidence on this point. It refers to the water in the Sutlej river in the Punjab at Rupar:—

——	July 7th, 1894.	July 29th, 1894.	June 13th, 1895.	August 14th, 1895.	July 30th, 1896.	July 6th, 1897.
Velocity of the river, feet per second ...	7·70	10·81	6·33	9·62	4·10	4·30
Proportion of silt to water by weight at the surface	$\frac{1}{89}$	$\frac{1}{127}$	$\frac{1}{59}$	$\frac{1}{82}$	$\frac{1}{535}$	$\frac{1}{300}$
Weight of silt at surface taken as unity ...	1·000	1·000	1·000	1·000	1·000	1·000
Weight at depth of 1·5 feet	1·015	1·127	1·217	1·036	1.042	1·067
" " 3·0 "	1·038	1·245	1·260	1·047	1·132	1·145
" " 4·5 "	1·038	1·358	1·329	1·056	1·202	1·152
" " 6·0 "	1·066	1·395	1·427	1·078	1·207	1·254
" " 7·5 "	1·084	1·581	1·496	1·088	1·395	1·383
" " 9·0 "	1·164	1·731	—	1·104	1·689	
" " 10·5 "	2·024	—	—	1·144	1·932	
" " 12·0 "	—	—	—	1·154		

The table shows a steady increase in the silt in the water as the depth increases, but the ratio of increase varies considerably.

Mr. Flynn[2] is responsible for the statement that the Durance in France carries in suspension 1 part of solid matter by weight to 33 of water, as an ordinary maximum, and that "in exceptional cases, as in August, 1858, the proportion was as high as $\frac{1}{10}$ of the water by weight." This is an enormous proportion, and can only be explained, apparently, on the supposition that the samples must have been taken immediately below a cutting bank of the river, or must have included matter travelling down the bed of the river itself. Mr. Wilson states[3] that 118 samples taken in the Rio Grande in New Mexico gave the volume of sediment as 0·345 per cent. of the volume of water; the percentage varied from 0·25 to 0·50 per cent. This would correspond to about 1 of silt by weight to 160 of weight by water. According to M. Surell's researches on the Rhine, which has a flood velocity of about 8 feet a second, the silt at the bottom is as much as 88 per cent. greater than that at the surface.

There is generally more silt in a rising flood than in a falling one. This is illustrated by the figures in the table on the next page, which are taken from experiments made by Mr. C. G. Livesay in 1893 on the river Bhagiratti in Bengal. The Bhagiratti is one of the great spill channels in the delta of the Ganges having a small slope and moderate velocity. It will be noticed that, while the proportion of silt is much smaller than in the Sutlej, the ratio of increase in the volume of it as the depth increases is greater. It has been said that the maximum amount of silt is generally found in a rising river before the height of the flood

[1] "Report on the Physics and Hydraulics of the Mississippi River," 1876, pages 134 *et seq.*

[2] "Irrigation Canals and other Irrigation Works," page 63.

[3] "Engineering Results of Irrigation Survey." Wilson, 1894.

—	River Rising.			River Falling.	
	August 12th.	August 15th.	August 20th.	November 1st.	November 6th.
Surface velocity of river. Feet per second...	3·6	3·6	3·5	3·4	3·4
Proportion of dry silt to water by weight at the surface of the river	$\frac{1}{1005}$	$\frac{1}{1641}$	$\frac{1}{1274}$	$\frac{1}{1710}$	$\frac{1}{1891}$
Weight of silt at surface taken as unity ...	1·000	1·000	1·000	1·000	1·000
Weight of silt at depth of 5 feet	1·421	1·407	1·326	1·164	1·167
" " 10 "	1·710	1·605	1·816	1·342	1·032
" " 15 "	2·280	1·802	2·489	1·342	1·500
" " 20 "	2·421	2·000	—	1·835	1·667
" " 25 "	—	2·456	—	—	2·000

has been reached. This is not, however, always the case. In a tidal river in Eastern Bengal[1] the following results were recorded:—

Time of observation.	Velocity of Current. Feet per Second.	Proportion of Dry Silt to Water by Weight.
Just after the flood tide began to flow ...	1·9	$\frac{1}{251}$
After flood had run one hour	3·6	$\frac{1}{202}$
" " " two hours	3·5	$\frac{1}{152}$
" " " three hours ...	2·8	$\frac{1}{70}$
At high water	0·0	$\frac{1}{25}$

In this case the volume of silt increased greatly, even with a decreasing velocity, with the rise of the tide. The river in question, the Russulpore, is one which is noted for its deep muddy banks, and the incoming tide stirs the silt up forcibly. The stronger the tide the larger the proportion of silt: this is shown by the following experiments, which were taken during spring tides in the same river, the highest springs being on the 15th of May. The samples of water were taken, on each day, at the top of the high tide:—

Date.	High Water Level.	Proportion of Dry Silt to Water by Weight.
May 12th, 1885	116·11	$\frac{1}{465}$
" 13th "	116·85	$\frac{1}{263}$
" 14th "	117·33	$\frac{1}{142}$
" 15th "	118·53	$\frac{1}{25}$
" 16th "	117·46	$\frac{1}{69}$
" 17th "	117·33	$\frac{1}{80}$

It will be noticed that the proportion of silt gradually reached its maximum on the day of the highest springs and then decreased as the height of the tide decreased.

Mr. Apjohn considered that 50 lbs. of dry silt and 45 lbs. of water went to make up 1 cubic foot of damp silt, as it is found deposited in the beds of rivers. He gives the following figures which,

[1] Lectures at Sibpur College in 1895 by Mr. J. H. Apjohn.

it must be remembered, are not maxima, but averages based on the number of experiments stated. The samples were taken near the surface of the rivers:—

Date.	Number of Experiments.	River.	Cubic Feet of Damp Silt in 100,000 Cubic Feet of Water.
1842	12	Hoogly at Calcutta	75
1894	79	Hoogly at Palta	54
1889	30	Tolly's Nullah (near Calcutta) ...	69
1893	14	Bhagiratti	65
1875 } 1885 }	78	Various tidal rivers on the east coast of Bengal	118
1885	21	" " "	62
Total ...	234	Mean of all the rivers	76

So the mean result of 234 experiments shows that Bengal rivers, in their tidal portions, carry a mean for the whole year at or near their surface of 76 parts of damp silt to 100,000 cubic feet of water. This corresponds to a proportion of $\frac{1}{1642}$ of dry silt to water by weight. The following table shows the maximum amounts of silt found in various well-known rivers :—

Name of River.	Approximate Velocity.	Experimenters	Proportion of Silt to Water by Weight
	Feet per second.		
Mississippi ...	—	Humfreys and Abbot ...	$\frac{1}{572}$
Rhone ...	8	Gorsse and Subours ...	$\frac{1}{45}$
Po	—	Lombardini	$\frac{1}{300}$
Vistula ...	10	Spittel	$\frac{1}{48}$
Rhine	—	Hartsoeker	$\frac{1}{100}$

The amounts of silt in the Vistula and Rhone appear extremely large: the amounts in the Vistula are said to have been recorded when the river was partly frozen. Experiments made on the Indus[1] gave the proportion of silt to water by weight in the flood season (end of July and early in August) as about an average of $\frac{1}{237}$, the velocity of the water being from $3\frac{1}{2}$ to 5 feet a second; an analysis of the silt showed that it contained about equal parts of sand and of rich fertilising mud. The Nile silt contains about the same proportion of fine sand, and Dr. Letheby[2] calculated that the proportion of silt to water in the flood of the Nile in August was $\frac{1}{660}$ by weight, but Sir William Willcocks put the proportion as $\frac{1}{670}$ by volume. Experiments were made on the Ganges by Mr. Medlicott,[3] near the head of the Ganges Canal, where the velocity is great (probably 10 to 12 feet a second), with the result that the maximum amount of silt found was $\frac{1}{123}$ by weight, and this appears to have been an extreme example and a somewhat doubtful one, an average of four examples in August and September giving only $\frac{1}{700}$. The Ganges at this point is fed mainly by the melting of the snows in the Himalayas, and the water

1 "Roorkee Professional Papers," 1st series, vol. ii., "Indus Silt Experiments," by Colonel Tremenheere, R.E., page 24.
2 "Proceedings of the Institution of Civil Engineers," vol. lx. page 376.
3 "Asiatic Society's Journal," vol. xx., parts 3 and 4.

is, consequently, comparatively free from silt; but in its lower reaches, after receiving the drainage of a large tract of country, the water is heavily charged with materials in suspension. Mr. Medlicott's experiments show that the water in the Ganges Canal at Roorkee, some eighteen miles from the point where the canal draws its supply from the river, is, at times of full supply, sometimes far more heavily charged with silt than the water in the river, the proportion of silt being as high as $\frac{1}{13}$. This circumstance is interesting as confirming the fact that water which is not fully charged with silt will pick up silt from the bed of a canal, even although its velocity in the canal is far less than it was in the river from which it was drawn.

The water in the river Sutlej has been regularly tested for silt near the head of the Sirhind Canal at Rupar. The tests give the volume of silt in each 18-inch layer from the surface. The following table[1] gives the facts for four successive years on those days when the river carried the largest amount of silt. So the figures given are maxima:—

Date.	Velocity of River. Feet per Second.	Proportion of Silt to Water by Weight at the Depths in Feet below the Surface given in the different columns.							
		0	1·5	3·0	4·5	6·0	7·5	9·0	10·5
July 7th, 1894 ...	7·81	$\frac{1}{69}$	$\frac{1}{68}$	$\frac{1}{66}$	$\frac{1}{66}$	$\frac{1}{64}$	$\frac{1}{63}$	$\frac{1}{59}$	$\frac{1}{34}$
June 13th, 1895 ...	6·33	$\frac{1}{59}$	$\frac{1}{50}$	$\frac{1}{48}$	$\frac{1}{45}$	$\frac{1}{42}$	$\frac{1}{40}$		
June 27th, 1896 ...	11·62	$\frac{1}{79}$	$\frac{1}{72}$	$\frac{1}{60}$	$\frac{1}{54}$	—			
July 12th, 1897 ...	8·70	$\frac{1}{78}$	$\frac{1}{75}$	$\frac{1}{72}$	$\frac{1}{63}$	$\frac{1}{57}$			

The volume of silt varies, of course, very greatly from day to day in the same month, according to the state of the river. In July, 1894, for instance, the silt at the surface of the river was 1 part by weight in 69 parts by weight of water; the day before the water had contained, at the same level, 1 part by weight in 180 parts of water, and the day after 1 part by weight in 216 parts by weight of water. The clear water of the Sutlej, in the cold weather, has contained as little as 1 part by weight of silt in 60,000 parts of water.

The water in the river Sone in Bengal, which feeds the Sone Canals, has been tested in the same manner as that of the Sutlej, with the following results:—

	Proportion of Silt to Water by Weight.
July 1st, 1896—3 feet below surface ...	$\frac{1}{290}$
" " 8 " " " ...	$\frac{1}{197}$
Aug. 8th, 1897—3 " " " ...	$\frac{1}{152}$
" " 7 " " " ...	$\frac{1}{109}$
July 4th, 1898—3 " " " ...	$\frac{1}{209}$
" " 6 " " " ...	$\frac{1}{146}$
July 5th, 1899—at the surface ...	$\frac{1}{446}$
" " 3 feet below surface ...	$\frac{1}{333}$

These figures, as in the case of those given for the Sutlej, are the maxima of each year. They show that the maximum volume of silt carried by the Sone is much less than that carried by the Sutlej.

The analysis of the silt carried in the waters of these rivers has been carried beyond the point necessary to determine the weight of the matter held in suspension in their waters. The sediment itself has, in a long series of experiments, been divided into its two main component

[1] From Punjab Irrigation Paper No. 9.

parts of clay and sand—the former constituent being, as a rule, one which it is desirable to admit, the latter, sand, being the one which it is, usually, desirable to exclude from a canal. The following statement shows the result of these tests in the river Sutlej at Rupar in 1895:—

—	Ounces of Silt (both Clay and Sand) in 10 Cubic Feet of Water.	Percentage, by Weight, of—	
		Clay.	Sand.
Average of 30 samples taken in June	47·91	66·7	33·3
,, 18 ,, ,, July	18·79	71·3	28·7
,, 26 ,, ,, August	50·23	79·9	20·1
,, 18 ,, ,, September	4·88	76·6	23·4

But in the Sone river the amount of sand is much less, as is shown by the following figures, which were the results of experiments made at Dehree in 1898:—

—	Ounces of Silt (both Clay and Sand) in 10 Cubic Feet of Water.	Percentage, by Weight, of—	
		Clay.	Sand.
Average of 12 samples taken in June	15·4	99·6	0·4
,, 32 ,, ,, July	32·0	90·6	9·4
,, 26 ,, ,, August	23·6	83·4	16·6
,, 22 ,, ,, September	7·1	95·4	4·6

The Punjab engineers have gone beyond this. They have made experiments to scrutinise the sand itself in order to determine the relative fineness of the grains of which it is composed. This is an important consideration under certain circumstances. A coarse sand will choke a canal, but a fine sand can be flushed away. If sand is dropped into still water the different grains will sink in it at different velocities. The coarse grains will reach the bottom first; the finest grains will take the longest time to do so. Consequently a standard of fineness is established by recording the velocities with which sand of various degrees of fineness will sink. Sand which falls in water at the rate of half a foot per second is defined as sand of $\bar{0}\cdot5$ grade; sand which falls at the rate of one-tenth of a foot in a second is called sand of $\bar{0}\cdot1$ grade. The analysis of a sample is made by dropping a certain volume of sand into a vertical tube full of water. The tube terminates in a graduated glass capable of containing the same volume of sand. The time which the sand takes to fill each graduation is noted. Thus the first grains in a sample may take 30 seconds to fall 6 feet, which is a velocity of 0·2 feet per second, so these particular grains are of grade $\overline{0\cdot2}$: the last grains may take 250 seconds to fall 5 feet, which is a velocity of 0·02, so the finest grains are of grade $\overline{0\cdot02}$, and the entire sample would be classed as $\frac{0\cdot02}{0\cdot2}$. Another sand might work out to class $\frac{0\cdot02}{0\cdot3}$, showing that the coarsest grains in it had a velocity of 0·3 feet in a second, and the finest a velocity of 0·02 feet. This analysis is useful in this way. Experience will show what grade of sand will be carried forward in a canal and what grade may lie for a long time, or perhaps permanently, in the bed and choke it. For instance, sand which remains in the main line of the Sirhind Canal

is almost all of coarser grain than grade $\overline{0 \cdot 10}$, and the coarsest sand which enters it is grade $\overline{0 \cdot 50}$. When the sand in the water entering the canal is found to be of class $\frac{0 \cdot 10}{0 \cdot 50}$, it is a clear intimation that the head-sluice should be closed until the sand in the water is of finer quality.

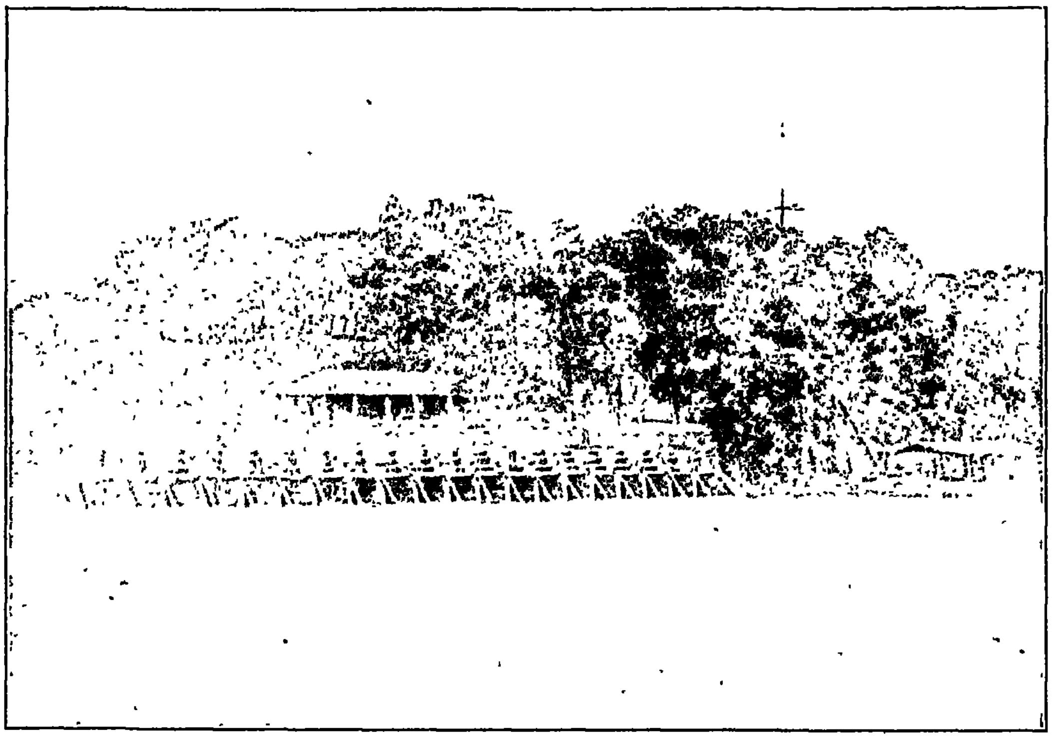
The investigations made into the quantity of silt in river water have led to some interesting calculations as to the quantity of solid matter which is carried to the sea by various rivers. Colonel Tremenheere estimated that the Indus, during the 100 days of flood, carried about 119 millions of cubic yards of silt to the sea, a quantity sufficient to cover 38 square miles to a depth of one yard. Sir Benjamin Baker[1] calculated that the Nile deposited 49½ million tons, or say 40 million cubic yards, in the Mediterranean during the year. Sir William Willcocks put the figure at 47 million cubic yards. The ordinary flood discharge of the Indus at Sukkur is about 400,000 cubic feet a second,[2] and that of the Nile at Assuan about 300,000 cubic feet a second. An instance of the rapidity with which the waters of the Nile will deposit silt, when the conditions induce a rapid settlement of the mud held in suspension, is given by Sir William Willcocks. He says[3]:—" I measured the rate of silt deposit under No. 2 arch of the Damietta Barrage, where there was slack water. The amount deposited was as follows:—

	Metres.
August 14th, 1886 ...	0·48
„ 15th, „ ...	0·15
„ 16th, „ ...	1·31
„ 17th, „ ...	1·10
„ 18th, „ ...	0·10
„ 19th, „ ...	0·50
Total ...	3·64 metres (12 feet)

of silt in six days of August. Between the 9th and 26th of August, or in eighteen days, 6·50 metres (21⅓ feet) of silt were deposited under that arch. The silt had then reached the height of the flood surface, and could rise no more." Another instance of rapid silting is given by Mr. David Stephenson, who states[4] that the channel between Dumbal Island and the shore near the mouth of the Avon was silted up to the extent of 32 feet in seven years.

One of the most important points to be considered before an irrigation work of any kind is undertaken is the amount and quality of the silt in the source from which the water is to be obtained. In the case of canals taking off rivers of high velocity, and which probably carry but little fertilising matter, but a good deal—at certain times—of sand or even of shingle, the problem is to design the head-works so as to exclude to the utmost the coarser materials lest they materially diminish the discharge of the canals. In the case of rivers with a more moderate velocity, the problem is how to arrange matters so that the heavier particles, which travel in the lower strata of the river, and which are sometimes swept along the bed of it more than actually held in suspension in its waters, may be excluded, and the lighter fertilising atoms may not only be taken into the canal but may be carried along it and its branches and finally deposited on the fields. Again, in rivers with still lower velocities, such as the Indus and the Nile, the problem is rather how to design the canals so as to carry to the fields all the silt which can be obtained.

[1] "Proceedings of the Institution of Civil Engineers," vol. lx., "The Nile," by B. Baker.
[2] "Roorkee Professional Papers," 1st series, vol. ii., page 27.
[3] "Report on Reservoirs in Egypt," by W. Willcocks, April, 1891.
[4] "Canal and River Engineering," page 367



SURFACE SUPPLY INLET, SONE CANALS.

MYAPUR REGULATOR AT THE HEAD OF THE GANGES CANAL.

Taking, first, rivers of high velocity, an instance of the partial blocking of a canal by shingle and boulders is seen at the head of the Ganges Canal at Myapore,[1] where the canal is drawn off a branch of the main river, which has a slope of about 10 feet a mile above the canal head. The Myapore dam was constructed across this branch, and the head-sluice of the canal was placed in the canal itself, about 350 feet back from the line of the dam. The dam was originally constructed with a series of small piers along the crest of it with openings of 10 feet between them. It was found that the shingle, travelling down the bed of the river, was obstructed by the dam and was deposited largely in the channel just above the head-sluice. The deposit of the shingle has been checked by the construction of seven powerful under-sluices in the dam each 20 feet wide and with a floor level 12 inches below the old one, and by the construction of a new head-sluice, across the head of the canal, on a line diagonal to the stream, so that the shingle is carried past it, and not deposited, in the comparatively quiet water of the channel between the weir and the head-sluice of the canal. The new sluice is so built that the water taken into the canal may, as far as possible, be drawn from the surface and not from below. This, in a case of this kind particularly, is a matter of great importance, for the shingle travels along the bed. The head of the Eastern Jumna Canal (Plate on page 130) is also on a branch from the main river, the Jumna. This branch has a fall of from 13 to 16 feet a mile, and it is remarkable how little shingle is carried into the canal, although the fact that shingle does travel down the branch which supplies the canal is proved by the fact that the floors of the two weirs at Fyzabad and Nowshera, which act as escapes to the channel above the canal head, are damaged by the blows they receive from the falling boulders. The draw of these escapes, one of which is immediately above the canal head at Nowshera, appears to be sufficient to clear away the shingle.

The Sone Canals, in Bengal, and the Sirhind Canal, in the Punjab, both afford most instructive lessons in the silt question. They both used to silt up, in the head reaches, to an extent which almost threatened the very existence of the canals. In both cases the difficulty has been successfully overcome. In the case of the Sirhind Canal it was, at one time, contemplated to entirely close the canals during alternate silting seasons; and, at another, to lay down a steam tramway to help in removing the deposits. In the Sone Canals a fleet of dredgers was employed for many years, at great expense, in removing the silt, which was, even then, kept down with difficulty. Now the condition of affairs is very different. To a large extent the coarser sands have been prevented from entering both the Sirhind and Sone Canals, and such deposits as do occur during the silting season are automatically removed by the action of the water itself. The main line of the Sirhind Canal, and one of the two main lines of the Sone Canal, were originally constructed thus :—

—	Sirhind.	Sone.
Width of base	200 feet	180 feet
Slope of bed	0·125 per thousand	0·094 per thousand
Velocity originally assumed ...	2·98 feet per second	2·44 feet per second

The slope of the bed and the velocity have been increased considerably, in both cases, at the heads of the canals.

The Sirhind Canal was designed, originally, to carry a depth of 6 feet of water, in the

[1] See sketch, page 134.

rabi (cold weather) season; the crest of the weir across the Sutlej was fixed at 6 feet above the floor of the head-sluice. Soon after the canal was opened (1882) it was found that heavy silt deposits occurred, and that, in order to force the *rabi* supply into the canal, it was necessary to raise the weir and to erect crest shutters on it. This was done in 1886: the tops of the new shutters were 10 feet above the floor of the head-sluice. This increase in the level of the weir pool gave the head necessary to ensure the discharge for the *rabi* season of 1887; but, in 1888, the silt in the bed of the canal had again increased, and it was found difficult to pass the volume required. The level of the weir pool was again increased, by raising the shutters (see sketch, page 156) to 13 feet above the head-sluice floor. For two years this proved sufficient, and it was thought that the required control had been obtained. The silt was still deposited in the canal, but it was constantly varying in volume: it increased largely in the silting season (August and September), but decreased as soon as clear water was run in the canal. The discharge of the canal was kept up to the highest point when the water was clear, and a portion of the silt was flushed out through two powerful escapes, about eleven miles from the head, and a portion was passed on down the canal. Until 1890 it was supposed that, taking one year with another, this system of working would prove permanently successful. All the silt was not, of course, removed from the canal. A "silt wedge," thickest at the head and tapering off gradually down the canal, remained in the bed; but it was hoped that this would not increase beyond a certain point. But it did do so. The year 1891 was an unfavourable one, and grave doubts were entertained whether it would be possible to get in the *rabi* discharge. The silt deposits in the month of May, which had always been regarded as a non-silting month, were unusually heavy, and alarming reports were sent in. It was found that the deposit, which had not previously exceeded 15 *million* cubic feet, had actually reached 23 million cubic feet in the first 20,000 feet of the canal. This meant 8 to 9 feet of silt over the canal bed immediately below the head regulator, or only 3 to 4 feet of water entering the canal—a most serious state of affairs.

The Punjab engineers have completely solved the problem and have overcome the difficulty. An elaborate system of analysis was established of samples of water which were taken in the river and in the canal at various places. Ten cubic feet of water were taken for each sample, and the total volume of silt (clay and sand) was ascertained: in most cases the silt samples were further investigated, and the relative volumes of clay and sand determined; in some cases the quality of the sand was gauged and classed as described on page 35.

One point of supreme importance which was determined was that only very light sands, which would be flushed out of the canal by the clear water, were held in suspension in the waters of the river. It was proved that all the coarse sand travelled along the bottom of the river and that the deposits in the canal, which were permanently prejudicial, were almost entirely due to coarse sand, rolled into the canal from the river bed.

The first improvement, which a knowledge of this fact suggested, was that the under-sluices of the weir should be kept closed as long as might be, so that there should be as little velocity as possible in the river immediately in front of the head-sluice of the canal. This restricts the flow of coarse sand along the river bed, and consequently reduces the flow of sand into the canal. It had been the practice on the Sone Canals, from the very commencement, to keep a high velocity in the river near the head-sluice by keeping one or two of the under-sluice gates next the canal open as long as possible. This was a measure eminently calculated to aid the silting of the canal, as indeed it did do to a very costly extent. If the under-sluices of the weir are closed, the river tends to silt up above them, and this may interfere with the discharge into the canal. The fact that the river bed is higher also increases the probability of the coarser

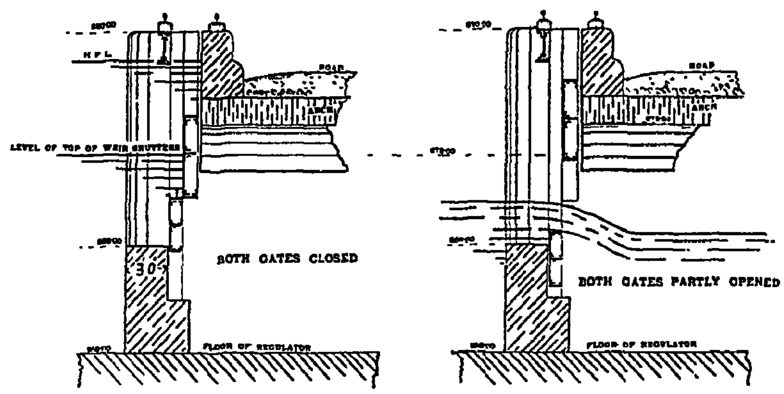
sands being lifted from it into the canal. On the Sone Canals it has been found that this silting in the river does not occur to a serious extent: the river bed does rise, if the under-sluices are long closed, but a good flood in the river diminishes the deposit sufficiently. On the Sirhind Canal special measures have been adopted, which are illustrated in the sketch on page 154. The river wall or "divide," which is shown on this sketch, was added to the weir long after its original construction. The object of it is to confine the current in front of the head-sluice, when the under-sluices are open, so as to flush out the deposits. The "divide" is about 700 feet long and 15 to 17 feet in height above the floor of the under-sluices. The plan of regulating is to keep all the under-sluices closed, and as many as possible of the crest shutters of the weir closed also. If it is necessary to open any of them, the weir shutters on the right bank of the river—that is, as far away from the canal as possible—are opened as a vent for the river water. The result is a pond of still water about 800 acres in surface area, averaging 12 feet in depth, and from this the canal is fed. When the silt, deposited between the "divide" and the head-sluice, exceeds 4 feet in depth the canal is closed for one day, the under-sluices are opened, and the deposits are cleared away.

The fact that it is rolling sand, drawn along the river bed, and not the sand held in suspension in the river water, which is so harmful, was illustrated, in the Sone Canals, by the fact that pebbles the size of hen's eggs were commonly dredged out of the canal. On those canals the head-sluice shutters were divided into two parts, the lower part being generally $4\frac{1}{2}$ feet high. The upper part of the shutters only used to be lifted, and the water was taken in, over the top of the lower one, $4\frac{1}{2}$ feet above the river bed. It was clearly proved that the amount of coarse sand, contained in the water passing into the canal, was very much greater than that contained in samples of the river water taken at the same level. It was the practice to open as few of the vents of the head-sluice as possible, and to open those ones sufficiently to ensure the required discharge. The result of this was to induce the maximum velocity through the vents which the relative levels of the river and canal could produce. A swirl was consequently created in front of the vents, which was sufficient to lift coarse sand and pebbles off the river bed. Even now, although this action has been largely stopped, it is very often found, on the Sone Canals, that the water entering the canal, at a particular level, contains much more sand than the water in the river, at the same level, only a hundred yards away. All these considerations point clearly to the importance of reducing the velocity in the river in front of the canal as much as possible.

The second point of importance was to admit the supply into the canal at as high a level as possible. The primary object of this was to reduce the velocity and agitation of the water in front of the sluice, and the secondary object was to take in water which contained a smaller proportion of silt. It may, perhaps, be thought that the second object was the more important of the two, but it is believed that the first is far more important than the second. The silt analyses seem to have established the fact that the sand, held in suspension in the water, 2, 3, or 4 feet below the surface, is rarely of a coarser grade than can be passed down the canal without harm, and it is undoubtedly the case that, when the velocity through the vents of the head-sluice is high, eddies are formed which suck up coarse sand from the river bed.

The Sirhind Canal head-sluice or regulator has thirteen bays of 21 feet span. These were, originally, divided by two jack piers in each bay, making thirty-nine vents of 5 feet each. These vents extended to the floor, and the custom was to keep "kurries" or baulks at the bottoms of the vents, about 3 feet or 4 feet high and to draw in the supply over these, regulating the discharge by the draw gates above the baulks. The system was, in fact, the same as that which was originally employed on the Sone Canals. It is believed

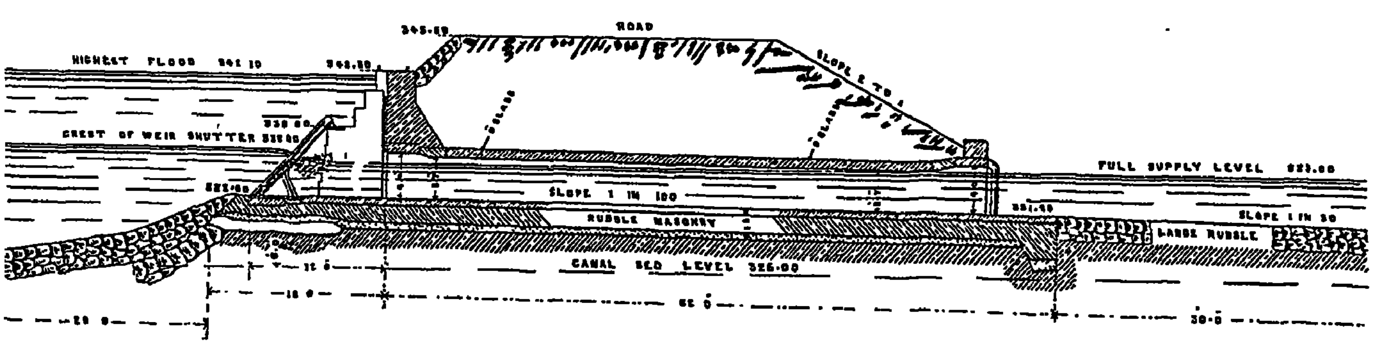
that the river bed silted up to the crest, or nearly to the crest of these lower baulks, and that the coarse sand, travelling along the bed, was drawn directly into the canal. The alteration which was made in the Sirhind Canal head-sluice is illustrated in this sketch :—



Shutters of Sirhind Canal Head Sluice.

The jack piers were removed and all the vents were made 21 feet wide. A breast wall, 7 feet high above the regulator floor, was built in all the thirteen bays, so that all the water drawn into the canal must be taken above that level. An iron gate 3 feet 6 inches deep by 21 feet long works behind the breast wall and can be raised 3 feet above it, so that the water, in that case, is drawn 10 feet above the sluice floor and 12 feet above the level of the under-sluice floor. Above this lower gate is another one, also 21 feet broad, which is used to close the vent entirely during floods. This alteration of the method of drawing the supply has had a most potent effect. The coarser sands are not now drawn up into the canal: the flushing of the channel in the river in front of the sluice, when the canal is closed, keeps down the level of the river bed; the restriction of velocity and swirl in front of the head-sluice, by drawing in a shallow film of uniform depth along the whole face of the sluice, prevents the action which used to suck up the coarser sands, and the general result is that the silt, which does accumulate in the canal in the silting season, is finer than it used to be, and, when the clear water comes, after the silting season is over, it is passed on, harmlessly, down the canal or out of the escapes.

On the Sone Canals a similar system has been adopted, with different arrangements. The original vents of the head-sluice have been left unaltered, but regulation is effected by "kurries" or baulks, over the tops of the lower shutters, which are all 4½ feet high. No breast wall has been built, as experience has shown that in the clear water season it is desirable to open all the vents down to the floor level, for, at that time, when the velocity through the vents is small, the coarse sand does not travel into the canal. In these canals the time of maximum demand for irrigation is during the silting season, and in this respect they are unlike the Sirhind Canal. It was found that the waterway in the original head-sluice or regulator, when it was restricted by the system of drawing only from the surface, was insufficient. A new work, called the "surface supply inlet," was built on the river bank, substantially to this section :—



Surface Supply Inlet, Sone Canals

This added very largely to the waterway at a high level. The floor of this inlet was 4 feet above the canal bed, and "kurries" were inserted in the cast-iron standards as occasion demanded. It is a strict rule that the level at which the "kurries" are placed is to be the same in the head-sluice and in the inlet, as nearly as possible, and that all the vents are to be used. This results, for any given discharge, in the minimum velocity and the least up-draught from the river bed.

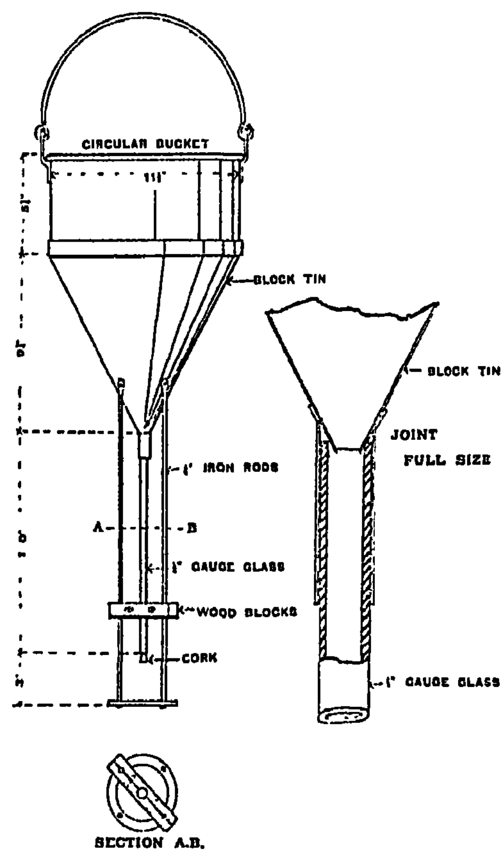
The three main causes, then, which have reduced the injurious silting in the Sirhind and Sone Canals are these—

First: The reduction in velocity in the river by closing the under-sluices as much as possible.

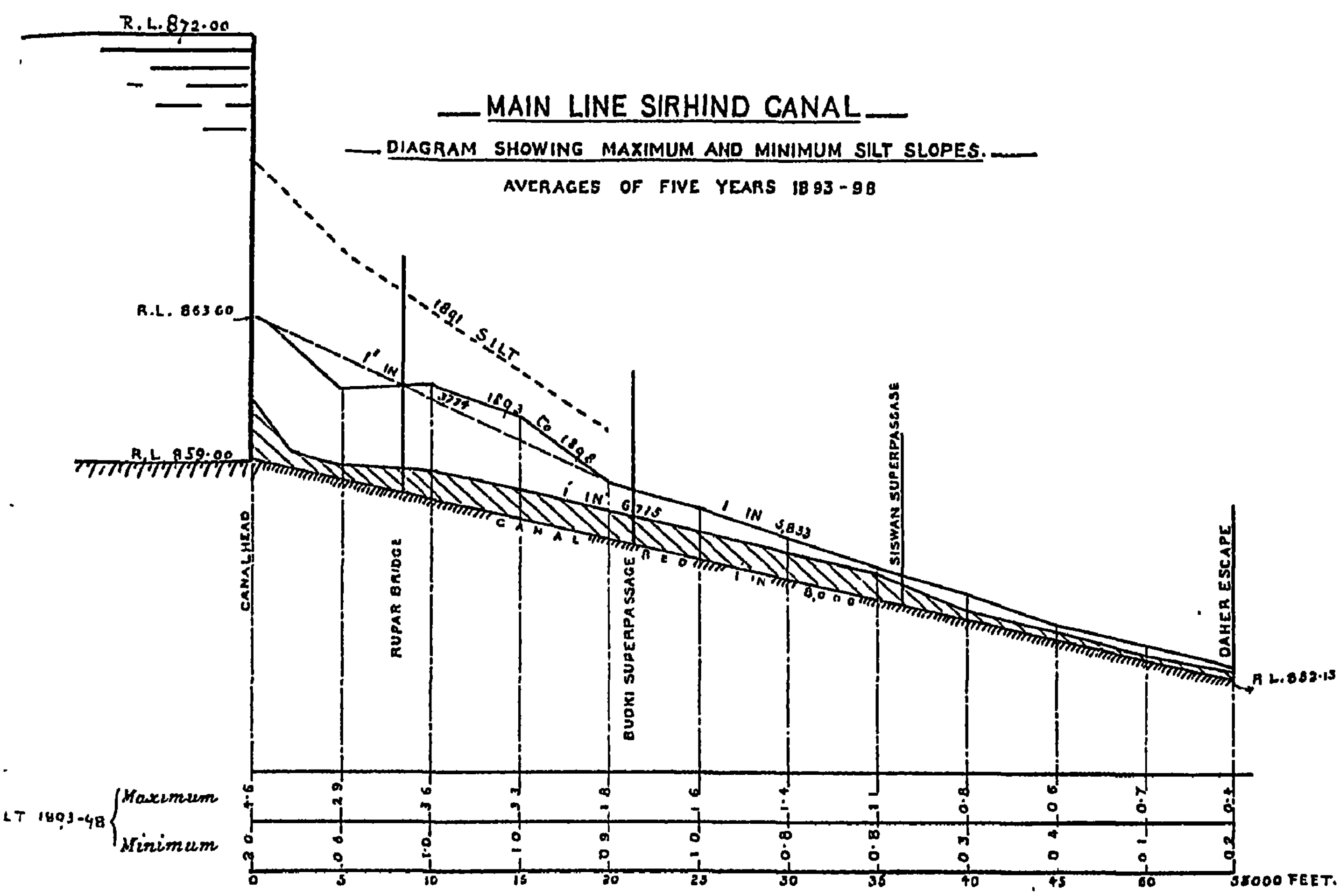
Secondly: The reduction of the velocity through the head-sluice by increasing the waterway and drawing the supply in as shallow a film as possible from as high a level as possible.

Thirdly: The closure of the canal during floods, when the under-sluices are necessarily open and there is a high velocity in front of the canal head.

The effect of this is to reduce the grade of sand which is deposited. But it is necessary, nevertheless,



SILT-TESTING BUCKET.



to take steps to remove the deposit which still occurs. This is done by a series of flushings. On the Sone Canals these flushings are carried on even in the silting season. But in the Sirhind Canal the flushings take place as soon as "snow water," *i.e.*, clear water, comes down the river. In the Sone Canals experience shows that, even in July and August, when the water in the river carries a good dealt of silt, it is advantageous to run as large discharges as possible, so long (1) as the under-sluices of the weir are closed, and (2) the water entering the canal does not carry sand coarser than a certain grade. The appliance shown in the sketch (page 41) is used as a rough guide to determine the quality of the sand which is coming in with the water. A sample of the water passing into the canal is poured into the bucket and the heavier sand is almost immediately deposited in the gauge-glass. After a certain time the water is poured off and the sand is then taken out of the gauge-glass by removing the cork. This is a rough-and-ready way of testing the water to see whether it is desirable to close the canal entirely. When the floods rise above definite levels, the canals are always entirely closed. It is the only way of preventing the deposit of large quantities of coarse sand.

The result of the measures adopted on the Sirhind Canal is illustrated in the diagram on page 41. The dotted line shows approximately the line of the deposit in May, 1891; the full lines show the average maximum and minimum deposits for a period of five years under the altered conditions which now obtain. It will be seen that, at the period of maximum deposit, the first 20,000 feet of the canal bed, as it then is, has a slope of 1 in 3,774, and at the time of minimum deposit the slope is 1 in 6,715, as compared with 1 in 8,000, to which the bed was originally excavated. The following table shows the volume of silt at the maximum and minimum periods, and gives a better idea than the diagram does of the great volume of silt, averaging about 15 million cubic feet, which used to be annually cleared out of the canal, or passed on down it to the fields, by the action of clear water. It shows also the immense reduction in the silting which has resulted, in late years, from the improvements effected in the regulation of the supply:—

SIRHIND CANAL.

Year.	Volume of Silt Deposit in the First 57,000 Feet of the Canal.		Volume of Silt Scoured away from the Bed of the Canal each Year.
	Maximum.	Minimum.	
	Cubic Feet.	Cubic Feet.	Cubic Feet.
1893 ...	20,253,000	11,336,000	—
1894 ...	18,719,000	10,000,000	10,253,000
1895 ...	21,834,000	6,823,000	11,896,000
1896 ...	21,083,000	7,903,000	13,931,000
1897 ...	24,904,000	7,378,000	13,705,000
1898 ...	?	6,706,000	18,198,000
1899 ...	?	?	?
1900 ...	20,854,000	7,011,000	?
1901 ...	8,217,000	2,382,000	18,472,000
1902 ...	5,641,000	2,400,000	5,817,000
1903 ...	6,737,000	1,584,000	5,153,000
1904 ...	?	1,422,000	5,315,000

It is worthy of notice that the velocity of the canal is but slightly greater during the scouring period than in the silting period. In August and September, 1894, the velocity was 3·2 and 3·0 feet per second respectively; $3\frac{3}{4}$ millions of cubic feet of silt were deposited. In

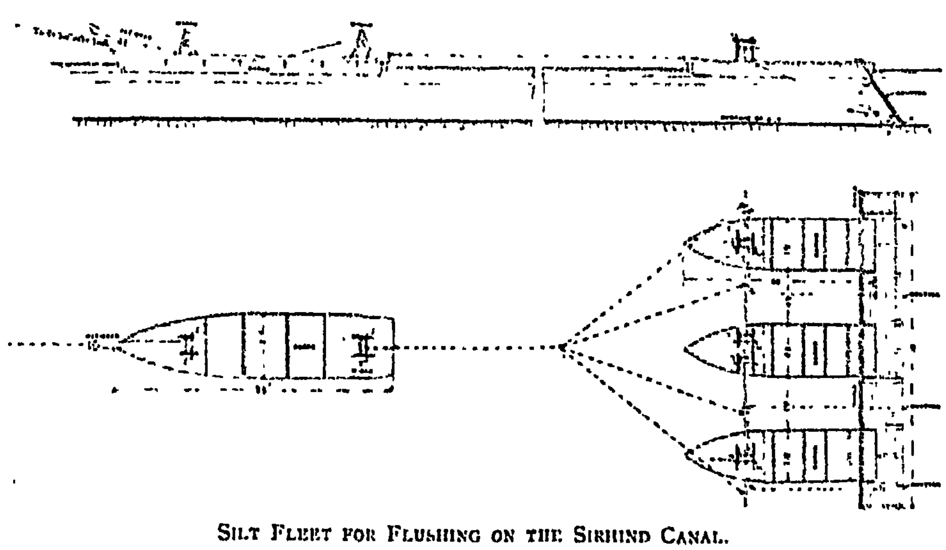
October and November the velocity was 3·5 and 3·3 feet and 8$\frac{3}{4}$ million cubic feet of silt passed out of the first reach of the canal. The silt is probably constantly in motion on the bed of the canal, even in the silting season, but, when the water is clear, a good deal of it is picked up by the water and carried away, the motion on the bed still continuing. The motion on the canal bed is clearly shown by diagrams which have been prepared, showing the silt at intervals of ten days. A distinct wave of silt can be traced passing forward down the canal.

On the Sone Canal the quantities of silt removed are not nearly so great as those on the Sirhind Canal, as the following table shows:—

SONE CANAL.

Volume of Deposit in the First 21,000 Feet of the Canal.		Volume of Silt Scoured away during the Year.
	Cubic Feet.	Cubic Feet.
July 20th, 1898	Maximum 5,100,000	
October 31st, 1898	Minimum 3,504,000	1,596,000
July 31st, 1899	Maximum 4,937,000	
December 5th, 1899	Minimum 3,509,000	1,428,000
October 2nd, 1900	Maximum 4,544,000	
November 10th, 1900	Minimum 3,889,000	655,000
July 18th, 1901	Maximum 4,450,000	
November 20th, 1901	Minimum 3,157,000	1,293,000
July 30th, 1902	Maximum 4,345,000	
December 11th, 1902	Minimum 3,563,000	782,000

But in this case, also, full command of the deposits has now been secured. Before the alterations, which have been described, were made, about 6 million cubic feet used to be dredged out of one of the Sone Canals every year at great expense. Now there is no dredging and no expenditure. The water carries forward all surplus deposits.



SILT FLEET FOR FLUSHING ON THE SIRHIND CANAL.

One method of aiding the scouring of the silt from a canal is illustrated in the sketch on this page. It shows a "silt fleet" which used to be employed some years ago on the Sirhind Canal in the Punjab.

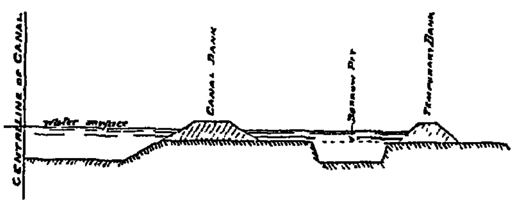
The shutters at the stern of the lower "fleet" of three united barges can be manipulated by the winches; the centre ones are usually kept at a fixed angle. The upper barge is moored, and the "fleet" carrying the shutters is gradually let down stream by the winch at the stern of the upper barge. When the shutter, on the left side of the row, is let go, the "fleet" swings to the left bank; when that shutter is drawn down to the surface of the silt, and the corresponding one on the right side is released, the three barges swing to the right bank. The shutters cause

the water to stir up the silt and it is washed forward. But a large proportion, probably at least 90 per cent., is deposited again, within a few hundred feet, unless the silt is very fine. The system is not very efficacious in anything but the finest material. In the muddy silt in the tidal reaches of Bengal rivers the same system was used with great effect.

On the Lower Ganges Canal, and in the Agra Canal, there are escapes back into the river, 1½ miles or 2 miles below the weir, which are sufficiently powerful to scour out the greater part of the silt which is deposited in the flood season. In these cases the silt is of an extremely fine nature, and a great deal is carried forward in the canals: no dredgers are employed. The scouring sluices are perhaps rather too close to the heads of the canals. In these cases the maximum velocity of the water is under 2·5 feet a second.

On the Sirhind Canal, on the Lower Ganges Canal, and on other canals in the Upper Provinces, a system has been tried for silting up the borrow pits, which have been cut to form the banks at the lower ends of the reaches where the canal is in embankment.

The borrow pits have in some cases been taken from the centre of the canal and in other cases from the outside beyond the canal bank. The former system was not satisfactory; the pits never silted up fully, abnormal side silting on the bermes occurred[1]; the pits were very dangerous to people wading across the canal, and a retrogression of levels occurred in some cases, the banks between the pits being scoured away. The system of central borrow pits must be condemned.



SIDE BORROW PITS

Another, and the most common, system was to cut the borrow pits outside the canal banks, as shown in this sketch. The borrow pits were made, in some cases, 500 to 1,000 feet long, in other cases as much as 4,000 to 5,000 feet long; in the case of the shorter ones the system was known as the "in and out" system. In the case of the longer pits the method was known as the "long reach" system. Under the "in and out" system inlets at the upper end and outlets at the lower end were provided, and a part of the canal supply flowed through the silting basin. This plan only succeeded to a small extent; the upper openings silted up, and the flow into the silting basin was reduced; it became necessary to clear the entrance frequently, and frequent changes of the sites of inlets and outlets were necessary. The system was found to be expensive, troublesome and slow.

The "long reach" system was worked differently: the whole discharge of the canal, and not a part only, was sent through the silting basin. This system worked better than the "in and out" system. It was found suitable in cases where canals crossed long lengths of low ground and where there was a considerable width of Government land to be silted up. In the Rakh branch of the Sirhind Canal, 329 lakhs of cubic feet of silt were laid down by this system in a series of reaches aggregating 37,000 feet in length and 185 feet in width. In this case it was found that masonry inlets or regulators were unnecessary, but that protection of the inlet banks, and in some cases of the outlet banks and cross bunds, by bushing was necessary.

But the most successful system for strengthening canal banks in parts where the canal is in embankment and the banks are high, is that known as the "internal silting" system. Under this system the canal banks are set back at some distance from the normal section of the canal channel, and inducements are given for the deposit of silt in the bermes. The banks are made

[1] Note by Mr. J. Benton, C.I.E., dated August 1st, 1904.

up from shallow internal borrow pits, not more than 2 to 3 feet deep in canals of 30 to 100 feet normal bed, and a series of spurs are made leading from the canal banks up to the margin of the normal bed; in cases where the canal bed level is much above ground level, it has been found advantageous to construct these spurs of brushwood. The spurs are formed of two lines of stakes and brushwood filling, which is so laid that water flows fairly freely through the spurs. It is unnecessary that the spurs should be carried up to full supply level, as canals, as a rule, do not carry full supply for some years after their construction, and experience has proved that the side bermes will continue to rise when once they have attained a height of 2 or 3 feet above the central part of the channel.

The Bari Doab Canal in the Punjab is one which affords much instruction in silt deposit. It draws its supply from a river of great velocity in the boulder formation, and the velocity of the canal is also very high; it is actually 8 feet a second at the head of the canal. The silt, which in this case is very sandy, is carried down the main channels by the high velocity and deposited in the heads of the minor channels, where, in course of years, huge silt banks, covering a considerable width of land, have accumulated. There are heavy shingle deposits in the first mile of the canal supply channel and in the first two miles of the Sulampur feeder. These lengths are cleared out annually, and the shingle is led back into the river, below the weir, in wagons and deposited there. Many of the channels have scoured or silted, in the course of many years, until they have assumed, partly by natural action and partly by artificial works, a state of "silt equilibrium," that is, they neither scour nor silt now, although they used to do so. The extra amount[1] of mud in the river water during the summer is deposited chiefly in the upper reaches in which the velocities of the stream are least; but it is again picked up and carried forward when the cold-weather pure water comes down, so that the further reaches of the canal system are, as a rule, about equally turbid all the year round. In this part of the system Mr. R. G. Kennedy made observations at thirty sites where no silting or scouring was in progress, the canal having been flowing for years in a state of permanent *régime* in its self-silted bed. At all these thirty sites it was found that the mean velocity and the depth of the water were very approximately related to each other by the equation

$$V = c.d^m = \cdot 84\ d^{0 \cdot 64},$$

that is, the mean or critical velocity in these thirty cases was just sufficient to prevent silting or scouring, when the depth was that determined by the equation. The channels in question were of a very varied nature: the width of base varied from 8 feet to 91 feet; the depth varied from 2·2 feet to 7 feet, and the velocities varied from 1·30 to 2·91 feet per second. Mr. Kennedy states that the above equation will usually serve in Indian canals, irrespective of the nature of the silt—that is, that a channel designed to fulfil the formula will not silt, whether the matter in suspension be mud, or fine sand, or fairly coarse sand. But he admits that on different canal systems the values of c and m in the formula $V = c.d^m$ may vary slightly. Mr. Kennedy gives the table shown on the next page. This may often be a useful guide; but it is necessary to bear in mind that the theory refers only to silt in suspension, and not to silt which is rolled along the bed of a channel. It is this latter silt which is, in most cases, that which gives the most trouble.

The sandy silt in the Bari Doab Canal travels, no doubt, not only in suspension in the water, but is also carried down along its bed. The heavy silting at the heads of the distributaries is due to a large extent to the sand being swept in along the bed. This has been proved

[1] Kennedy on the Prevention of Silting, page 280, Proc. Inst. C.E., vol. cxix.

by the fact that a considerable improvement was effected in some cases by drawing the water into the distributaries, from the main canal, from the surface of the main stream instead of from the level of the bed. The distributaries on the Bari Doab Canal do not silt as badly now as they used to do, partly, it is thought, because they have been remodelled on Kennedy's method —that is, the velocity of the water in each channel is kept as near V_o (the critical velocity)[1] as possible. Mr. Kennedy's theory has given results on the Bari Doab Canal which are apparently satisfactory, as channels which used to silt badly no longer do so. Exceptions, however,[2] occur, and there are some doubts how far the results obtained are due to the remodelling. In some cases it is not possible to get the necessary slope, and the velocity in the channel is then less than the critical velocity and the channel silts; but on the whole of the Canal there are now very few such silting channels. As a further precaution against silting the Bari Doab distributaries are worked, as far as possible, with full supply whenever

MINIMUM LONGITUDINAL SLOPES OF, AND VELOCITIES OF FLOW IN, CHANNELS REQUIRED TO PREVENT SILTING FOR GIVEN DISCHARGES AND FOR VARIOUS DEPTHS OF FULL SUPPLY.

Calculated for N = 0·02375 in Kutter's formula.

Discharge in Cubic Feet per Second	For Maximum Probable Depths.			For Moderate Depths			For Minimum Probable Depths.		
	Depth in Feet.	Minimum Mean Velocity.	Minimum Fall per 1,000.	Depth in Feet	Minimum Mean Velocity.	Minimum Fall per 1,000.	Depth in Feet.	Minimum Mean Velocity.	Minimum Fall per 1,000
10	2·1	1·30	0·50	2·0	1·30	0·48	1·8	1·21	0·43
25	2·5	1·51	0·43	2·4	1·46	0·37	2·2	1·39	0·34
50	3·1	1·74	0·34	2·9	1·66	0·31	2·6	1·55	0·29
100	3·7	1·94	0·31	3·3	1·82	0·28	3·0	1·70	0·26
150	4·2	2·10	0·29	3·7	1·95	0·26	3·4	1·85	0·25
200	4·5	2·20	0·27	4·0	2·04	0·24	3·6	1·91	0·23
300	5·0	2·35	0·26	4·5	2·20	0·23	4·0	2·04	0·22
400	5·5	2·50	0·25	4·8	2·29	0·22	4·3	2·13	0·22
600	6·1	2·66	0·24	5·3	2·44	0·21	4·8	2·29	0·21
800	6·6	2·80	0·23	5·8	2·62	0·21	5·2	2·41	0·20
1,000	7·0	2·92	0·22	6·0	2·64	0·20	5·4	2·47	0·19
1,500	7·8	3·12	0·21	6·8	2·85	0·20	6·1	2·66	0·19
2,000	8·5	3·31	0·20	7·3	3·00	0·19	6·6	2·80	0·18

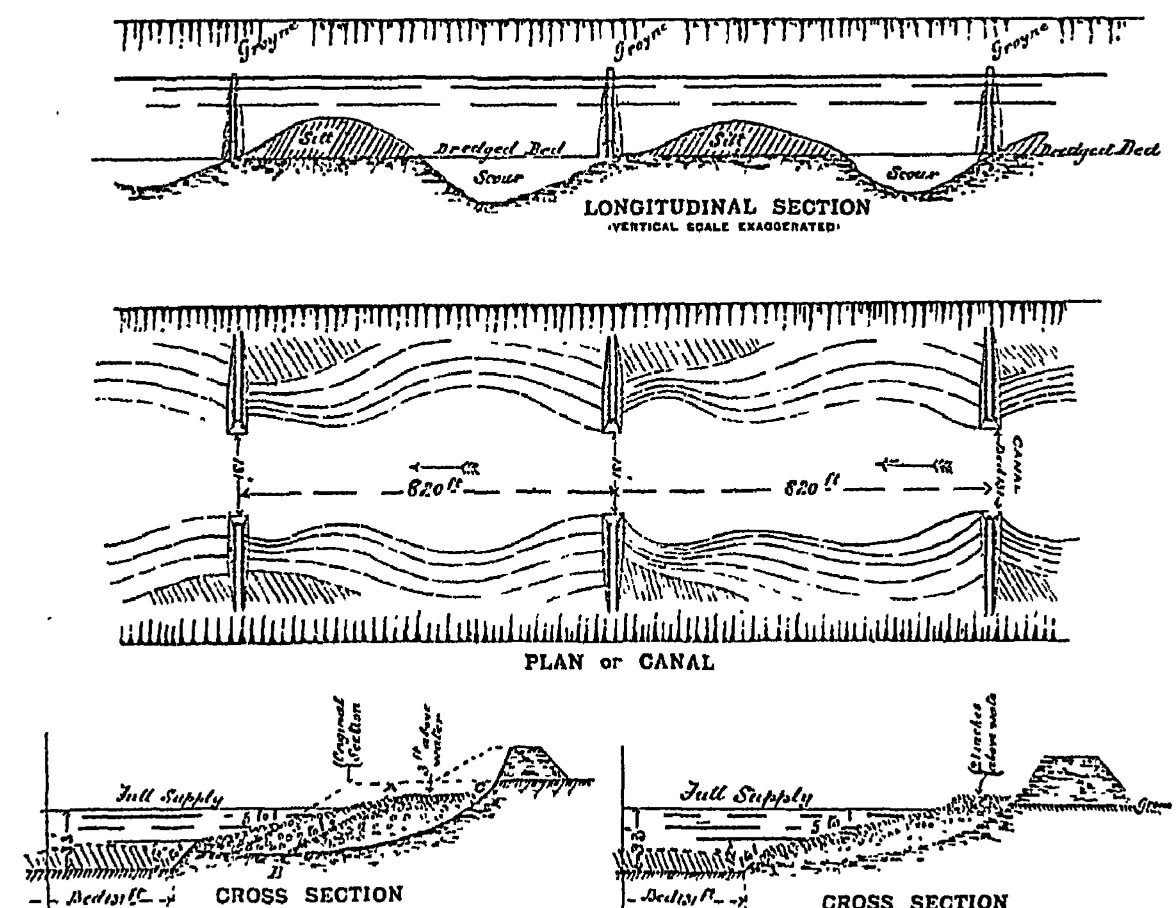
open. If the demand is not sufficient for full supply the distributary remains closed. Intermediate supplies are avoided. Thus, a distributary intended to carry 50 cubic feet per second would always run that quantity when open, and therefore it assumes a *régime* suitable for that volume, and, having done so, ceases to silt any more.

Internal regulation on the distributaries has been abolished. When the distributary is open to full supply, all the irrigation outlets on that distributary receive a supply of water. It follows that every portion of the distributary can assume and maintain a *régime* exactly suited to the supply which is carried by that portion of the distributary. Irrigation outlets are built with the bottom of the outlet level with the bed of the distributary, and they tend to clear off the silt which passes down the bed of the distributary. Irrigation watercourses (which are maintained by the irrigators) do still continue to silt; indeed, it seems probable that the measures adopted to stop the silting in the distributaries has tended to increase the deposits in the village watercourses. No remedy has been proposed. Something might perhaps be

[1] See "Kennedy's Diagrams of Discharge of Irrigation Channels."
[2] Note by Mr. Frost, Superintending Engineer.

done by insisting on the silt being cleared, regularly, to proper bed levels and cross sections, and by regular grading; but the irrigators do not willingly accept interference with the silt clearance of their watercourses. The silt which has collected in distributaries in former years has not been removed. The channels now run on the top of the old silt; the water level of the supplying canal has been raised by weirs or regulators if necessary, in order to obtain the necessary command. This fact shows how extensive the silting on this particular canal has been.

In the Bari Doab Canal the silt is very sandy, and therefore not advantageous to the soil; but in other canals, such, for instance, as the Orissa Canals taking off the Mahanuddee river on the east coast, and in the Sone Canals in Behar, the silt is almost entirely advantageous to the



GROYNES ON THE IBRAHIMIAH CANAL.

land, and it is desirable to distribute it as widely as possible over the fields. The cultivators in Orissa and Behar, during the rainy season, when the rice crop is under irrigation, will often endeavour to drain the water off their fields and irrigate them again from the canals whenever a freshet in the river brings an extra quantity of silt into the water.

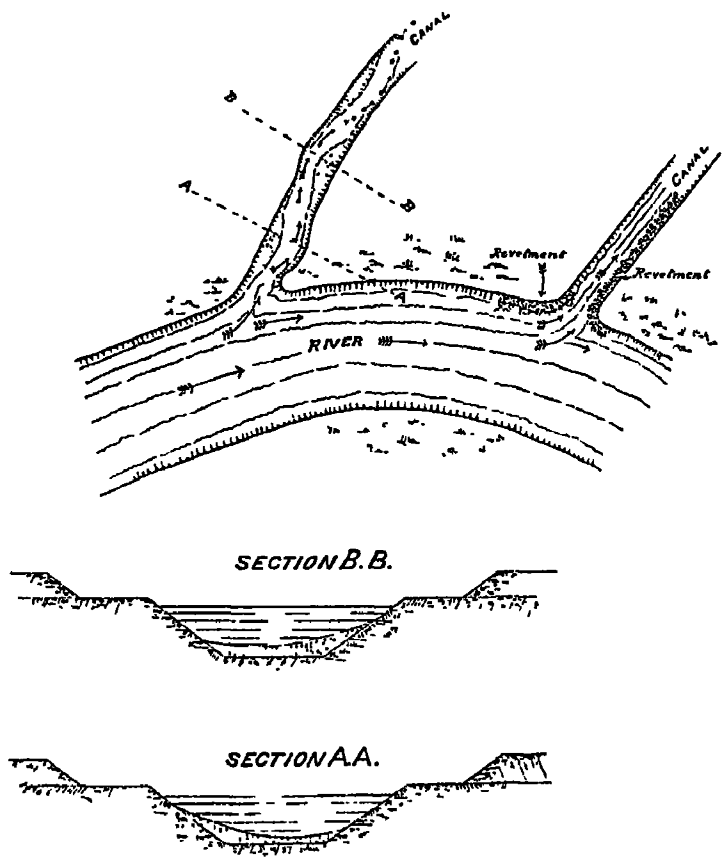
In many cases it is, no doubt, the case that the deposit of silt in canals is due to the velocity of the water being insufficient to carry forward the matter in suspension. But it may also be due to too high a velocity when the canal is running in full volume. Too high a velocity scours the banks, and the material is thrown down into the bed, where, when the discharge is reduced and the surface of the canal is lower, it greatly prejudices the effective discharge of the canal. There are two well-known instances of this in Egypt. In both cases the difficulty has been overcome by the same measures. A description of one case will suffice. The Ibrahimiah

Canal in Middle Egypt has only quite recently been provided with a head-sluice: it had formerly an open head from the Nile. It was, and is, a perennial canal, which in high Nile used to carry more than 30,000 cubic feet a second. During the periods of high discharge the banks cut away and the bed used to fill up, so that in some places the current divided into two parts flowing under either bank, and the supply in the time of low Nile was greatly reduced in consequence. The heavy deposits in the canal used to be dredged out at a cost of some £25,000 a year. The canal had a bed width of about 200 feet, and a surface slope in the flood season of $\frac{1}{13000}$ (= 0·08 per 1,000) with a velocity of about 4 feet a second. Rubble stone spurs have been employed, for some years, in this case with excellent results. The spurs, which are shown in the sketch on page 47, have been constructed in pairs, immediately opposite each other, with a crest slope of 1 in 5 and side slopes of 1 to 1. They are placed generally about 800 feet apart (four in each kilometre). The bed width has been reduced to 131 feet (40 metres), and it is dredged annually to fixed bed levels which give a slope of $\frac{1}{15000}$ (= 0·07 per 1,000). The groynes which are illustrated in this sketch are two metres thick at the crest, with side slopes of 1 to 1. They vary in elevation, according to the width of the channel. The 1 to 1 slope, at the point of each groyne, terminates, in all cases, at the margin of the new bed. The upper surface of each groyne has a slope of 1 in 5. Where the line of this slope cuts the water line before it cuts the bank, the groyne is made as shown in the right-hand cross section. But, when the point of intersection of this slope and the water line is more than 10 feet from the bank, the portion A B C, as shown in the left-hand section, is added: this portion has a hearting of earth, otherwise the groynes are entirely of rubble stone. The result of these groynes has been to check the cutting of the banks, and to cause the side slopes between the groynes to silt up to a certain extent, as is shown by the contour lines in the plan. The bed of the canal scours below each groyne and silts above it to varying depths and heights, while the silting on the side slopes, which are protected by the groynes, is greatest above and least below each groyne. In some cases the eddy below a groyne and the scour of the bed have been sufficient to undermine the spur, and it has had to be reconstructed. The silting on the side slopes is tending to restore the true section of the canal, and the action on the bed has enabled a larger summer supply to be passed with much less dredging. The groynes were first commenced in 1886, when 12 pairs were built. They have been extended year by year, up to 1896, when 216 pairs, extending for a length of 34 miles, had been constructed, at a gross cost of about £45,000. Grass and willows have been planted in many parts on the newly deposited silt at the edge of the low level of the water, to protect the bank and to encourage the deposit. The result has been successful. Before the groynes were commenced about 600,000 cubic metres of silt were dredged yearly from the canal, at a cost of about £25,000. In 1902 about 100,000 cubic metres were dredged, at a cost of £7,000.

The canal called the Rayah Behera, which takes off the Nile above the Barrage at Cairo, was even in a worse condition than the one just described. It has been remodelled on the same lines, with the result that its usefulness has been enormously increased.

Large quantities of silt are excavated every year from the inundation canals of Sind and the Punjab: the silt accumulations sometimes become so great that it is cheaper to cut a new head altogether than to continue to lift the silt over the accumulation of former years. In Egypt also the annual clearances from inundation canals are enormous. It is remarkable that, although the great majority of inundation canals silt more or less, the amount of silt varies greatly in different canals taking off the same river, and in some there is actually hardly any silt at all. So that it might be thought that it would be possible to construct inundation canals which would not silt. It is certain, however, that this is not possible under some conditions—as, for

instance, when a canal has to be taken off a cutting bank—but there is no doubt that much of the silting which now occurs might be avoided. One of the most essential points—to which very little attention is often given—is the proper grading and sectioning of canals: many old inundation canals are too large at their offtake from the river, and the reaches below are unable to carry the quantities which the upper reaches are capable of discharging. The result is that the velocities are checked in the higher reaches, and silt is deposited. It seems to be a fact which cannot be easily explained, that, under some circumstances, the deposit of silt is not so much caused by the actual diminution of velocity in the water, when it is drawn from a river into a canal, as by variations in the velocity after the water has entered the canal. There is no doubt that silt[1] encourages silt, and that a canal which is regularly aligned, truly graded, clean in section, which has well laid out curves of large radius, and in which the discharge introduced at the head is regularly disposed of, either on to the fields or by escapes, without alteration of velocity, will silt less than one of higher general velocity which is badly aligned and graded, and in which there is frequent interference by regulators. A very substantial decrease has been effected in the silt clearance of some canals by attention to this principle. It has been already noticed that one of the most certain means of making the head of an inundation canal silt is to regulate the discharge by a masonry work situated some distance from the head. Experience in Egypt has shown that one cause of silting is the oscillation which is set up in a canal by the form of entrance from the river. When a canal is taken off at an abrupt angle, the lower bank cuts away, below the head, and the current is deflected as shown in the sketch; the oscillation of the current, which often extends a long way, causes a deposit of silt in the bights, and the erosion, probably, of the bank at the bends: the cross sections show the result. It has been found that if the down-stream bank of the canal, for some distance below the head, and the up-stream bank immediately at the head, are revetted with stone, so that the erosion of the bank is stopped, and the oscillation checked, the amount of silt is reduced, although the velocity is unaltered. The flow of the stream is directed along the line of the axis of the canal, instead of oscillating from side to side of it.



HEADS OF EGYPTIAN INUNDATION CANALS.

[1] Report by Colonel Justin Ross, C.M.G., 1889, page 42.

CHAPTER IV.

FLOW-OFF FROM CATCHMENT AREAS, EVAPORATION, ABSORPTION.

Necessity for Reservoirs—Reservoirs liable to fail when most required—Maximum Discharge from a Catchment—Coefficients in Dickens' and Ryves' Formulæ—Maximum Discharge from small Catchments—Average Flow off a Catchment—Flow-off Dependent on Condition of Catchment—Loss by Evaporation and Absorption in Reservoirs—Absorption checked by Silt—Instances of Loss of Water in Canals by Evaporation and Absorption.

WORKS, for the storage of water for purposes of irrigation, are necessary in India wherever the rainfall, together with the minimum discharge of the rivers or streams of the neighbourhood, are insufficient for the crops. In many parts, as in Baluchistan and Rajputana, the streams may be torrents for a few days, and almost dry—or even quite dry—for the rest of the year. In the higher lands, where the rivers have comparatively small catchments and the slope of the ground is rapid, the rainfall, except in heavily wooded districts, passes off rapidly, and little is available for irrigation in the dry weather, unless reservoirs are formed in gorges in the hills.

One of the most important matters, in connection with any tank or reservoir project, is to ascertain the amount of water which may be expected to flow into the impounding basin. Not a few reservoirs have been constructed which have never filled to more than a fraction of their capacity, and, not unfrequently, the error has been caused by accepting the rainfall data of one or two stations as a true gauge of the fall over the entire catchment area of the reservoir. Too much care can hardly be taken to get as many observations as possible in different sites in the catchment. It has also to be borne in mind that the supply in a reservoir is most required during a year of abnormally deficient rainfall, and, in such a year, the supply to the reservoir is least. Years of abnormally deficient rainfall occur at long intervals, and may not be displayed in the returns which may be available of any particular locality; so it is well in preparing a project to allow a liberal discount on the available data. It does not, of course, follow that a tank or reservoir will be entirely useless because it may prove to be so in an abnormal year—the results obtained in ordinary years may possibly justify its construction; but instances are not wanting in which a reservoir was hardly necessary in ordinary years and failed to be of any service at all when scanty rainfall produced a demand which could not be supplied.

But, even if the rainfall returns of any particular catchment are complete, there is often no little difficulty in deciding, first, the maximum discharge from the catchment in periods of maximum rainfall; and, secondly, the amount of "flow-off" or the proportion of the total rainfall which will be discharged off the catchment. It is necessary to estimate the first quantity in order to design the bye-wash or escape from the reservoir, and the second is essential, in order that an estimate may be framed of the amount of water which will be stored. The proportion of the rainfall which is lost by evaporation and absorption is very large. The absorption varies, of course, greatly with the nature of the soil and the evaporation with the temperature and hygrometric condition of the air. The Indian Irrigation Commission[1] (1901—1903) estimated that the surface flow in the rivers of India aggregated only 41 per cent.

[1] Page 14, para. 53, "Report of Indian Irrigation Commission," 1901–1903.

of the rainfall. Mr. G. T. Perram, in a careful series of investigations, made on a small catchment in Southern India,[1] where the surface was gravelly soil and disintegrated rock overlying granite, almost entirely covered with lanthana scrub jungle, found that only 37 per cent. of the annual rainfall was drained off.

The maximum discharge from any given catchment is a factor which enters into many problems in connection with irrigation works and embankments. It depends primarily (1) on the maximum rainfall; (2) on the nature of the soil; (3) on the surface slope of the soil of the catchment; (4) on the area and configuration of the catchment; and (5) on the situation of it with reference to the monsoon current. No formula has yet been proposed which deals adequately with the problem. The two most commonly used are Dickens' formula $D = C\sqrt[4]{M^3}$, and Ryves' formula $D = C\sqrt[3]{M^2}$ (where D = discharge in cubic feet per second, M = the area of catchment in square miles, and C is a coefficient). These depend for their usefulness entirely on the value given to the coefficient C, which varies, as a matter of fact, from 150 to 1,000, and even to more than 1,000 in very abnormal cases. The following table shows the maximum discharges in certain well-known Indian rivers :—

Province.	Name of River.	Approximate Length of Channel of River in Miles.	Approximate Average Annual Rainfall in the Catchment in Inches.	Area of Catchment in Square Miles.	Maximum Discharge in Cubic Feet per Second.	Discharge in Cubic Feet per Second per Square Mile of Catchment.	Depth of "Flow-off" from the Catchment in Inches over the entire Catchment in 24 Hours.	Coefficients in Dickens' Formula, $D = C\sqrt[4]{M^3}$
Madras[2] ...	Cauvery ...	472	30 to 40	27,700	320,000	11	0·4	149
	Vellar ...	?	30 to 40	1,600	85,000	53	1·9	336
	Manjera ...	?	?	6,500	410,000	63	2·3	567
Bengal... ...	Sone ...	325	40 to 50	23,000	830,000	36	1·3	444
Orissa	Mahanuddee	520	50 to 70	45,000	1,570,000	35	1·3	508
United Provinces	Betwa ...	360	30 to 40	9,800	750,000[3]	83	3·0	811
Do. ...	Kali Nadi...	150	30 to 40	2,377	130,000	55	2·0	382
Punjab... ...	Chenab ...	350	30 to 50	11,400	700,000	61	2·3	630

A comparison of some of these is interesting as displaying the difficulties of assessing the proper coefficient to apply to Dickens' formula. In the case of the Sone and Mahanuddee, for instance, the larger coefficient in the latter case is probably mainly due to the greater rainfall; but in the cases of the Vellar and the Betwa, where the rainfall is about the same, the cause of the enormous discharge in the latter case is the nature of the catchment area itself. The catchment of the Vellar is believed to be generally thickly wooded, but the Chief Engineer of the North-West Provinces[4] speaks of the Betwa as "leaping down from the high lands of Central India to the level of the valley of the Jumna in channels . . . worn in the vast table of granite and trap rock which covers the country"; and he assumed that 80 per cent. of the rainfall over the entire catchment might be drained off it by the river. The large discharge obtained from the Manjera, which is a tributary of the Godaveri, is held to be due to the "basin being long and narrow, with the length lying generally in the direction of the monsoon current": it is a good example of the effect which may be produced by the configuration and situation of a comparatively small basin. The Kali Nadi is a remarkable case of a flow-off which is

[1] Page 319, vol. cxiii., "Proceedings of the Institution of Civil Engineers."
[2] Taken from "Madras Irrigation Manual," 1890.
[3] There is some doubt whether the discharge is not greater than this.
[4] Report by Colonel Greathed, Chief Engineer N.W.P., dated Nov. 2nd, 1874.

considered to have been unprecedented in the United Provinces. The Nadi drains a narrow basin, and passes under the Lower Ganges Canal through an aqueduct. This aqueduct was originally built on the hypothesis[1] that the maximum drainage off the catchment would be 9 cubic feet per second per square mile, or 0·33 inches in depth over the entire catchment in twenty-four hours. But the actual discharge of a flood in July, 1885, was just six times as great, and the result was the entire destruction of the aqueduct.

The maximum discharge from large catchments is greatly affected by the reservoir capacity of the river channel itself, and, in such rivers as the Ganges, by the volume held back in the vast areas which are flooded on either side of the river in great floods. The maximum flood discharge of the Ganges at Sahibgunge (above the head of the delta), is given[2] as 1,500,000 cubic feet a second, which is considerably less than the united discharges of the Ganges, Gogra, Sone, and Gunduk in ordinary floods at their confluence near the city of Patna. The Ganges has a total length of about 1,500 miles, and a catchment of 390,000 square miles, on which the average annual rainfall is from 40 to 60 inches. The Godavery river in Madras drains 115,570[3] square miles of country, subject to an average annual rainfall of 30 to 40 inches, and has a channel 900 miles in length: its maximum discharge is given as 1,000,000 cubic feet. The great difference in these two cases is primarily due to the gentler slope of the valley of the Ganges and the large reservoir capacity of the channel and spills of that river.

The statements on the opposite page[4] give the drainage areas of some of the principal rivers in the United Provinces.

It will be noticed that the maximum flood discharge of both the Jumna and Ganges rivers at Khara and Hardwar respectively, where they debouch from the Himalayas, is very considerably more than it is at Okhla and Narora, 135 miles lower down. The reason of this is that both these rivers, throughout this part of their courses, run in low-lying valleys which become flooded to a mile and more in width in places. These valleys act as flood reservoirs, so that, while the floods are prolonged, they are not nearly so great in volume in the lower as in the higher points.

The Betwa, the Ken, Dassan and Tons rivers all have their source in the highlands of Central India; the catchment area is generally rocky with steep slopes.

These facts give some guide to the maximum discharges to be expected from large areas in India, but no method has been as yet ascertained for fixing the value of the coefficient in the formulæ which are usually employed. All that can be done is to take the nearest parallel case which can be found, of which the data are known, and to estimate the coefficient according to the variation in the circumstances. In Madras, Ryves' formula ($D = C\sqrt[3]{M^2}$) is generally used with the co-efficient

$C = 450$, within 15 miles of the coast.
$= 563$, for the tract 15 to 100 miles from the coast.
$= 675$, for limited areas near the hills.

This is sometimes modified into the expression $D = C\sqrt[3]{M^2} - c\sqrt[3]{m^2}$, where c is taken as $\frac{1}{5}$ C, M being the whole catchment of the tract in square miles, and m the free catchment, *i.e.*, the basin of the tank itself.

The maximum discharge from small catchment areas varies, of course, more largely than that from larger ones, according to the effect produced by the five causes which have been

1 "Note on the Failure of the Kali Nadi Aqueduct," by the Inspector-General of Irrigation, August, 1885.
2 "Project for a Navigable Canal from the Ganges at Sahibgunge," by Colonel G. A. Searle.
3 "Madras Irrigation Manual," 1890.
4 Note by Mr. Hutton, Superintending Engineer, United Provinces.

TABLE OF CATCHMENT AREAS AND DISCHARGES OF SOME RIVERS IN THE UNITED PROVINCES OF AGRA AND OUDH.

Name of River.	Catchment in Hills.			Catchment in Plains.			Total Catchment.		Volumes Discharged in Cubic Feet per Second.					Flood Discharge per Square Mile of	
	Position.	Area in Square Miles.	Length of Basin in Miles.	Position.	Area in Square Miles.	Length of Basin in Miles.	Area in Square Miles.	Length of Basin in Miles.	Site of Observation.	Maximum. Year.	Maximum. Discharge.	Minimum. Year.	Minimum. Discharge.	Hill Catchment.	Total Catchment.
											Cub. Ft. per Sec.		Cub. Ft. per Sec.	Cub. Ft. per Sec.	Cub. Ft per Sec.
Jumna ...	Above Khara	4,500	90	Khara to Okhla	2,500	135	7,000	225	At Khara	1897	218,000	1900	2,124	48·44	—
									,, Okhla	1875	116,000	1879	375	—	16·57
Ganges ...	Above Hardwar	9,800	140	Hardwar to Narora	2,900	135	12,700	275	,, Hardwar	1880	610,668	1892	4,848	62·31	
									,, Narora	1880	280,000	1879	1,014	—	22·05
Hindan ...	—	—	—	Above Hindan Dam at Ghaziabad	2,300	120	2,300	120	,, Ghaziabad	1880	100,000	1878	190	—	43·48
Ramganga	Above Kalagarh	1,600	65	Kalagarh to Junction of Koh River	700	30	2,300	95	,, Kalagarh	1870	31,000	1869	50		
Betwa ...	—	—	—	Above Paricha	9,800	210	9,800	210	,, Paricha	1882	775,000	—	*Nil*	—	79·08
Ken ...	—	—	—	Above Baryarpur (proposed Canal Head)	7,900	155	7,900	155	,, Baryarpur	1874	450,000	1878	6	—	56·96
Dassan ...	—	—	—	Above Garotha	3,800	165	3,800	165	,, Burwa	1870	473,560	—	*Nil*	—	124·62
Tons ...	—	—	—	Above Lonipur (proposed Canal Head)	3,400	95	3,400	95	,, Lonipur	1875	230,000	—	,,	—	67·65
									,, Mawaiya	1875	450,000	—	,,		
Sarda ...	Above Baramdeo	6,350	105	Baramdeo to Alengaing	1,000	50	7,350	155	,, Kataiya	1880	355,000	1869	4,000	—	48·30
Gunti ...	—	—	—	Above Lucknow	3,700	155	3,700	155	,, Muhamdi	1894	45,814	—	—		
									,, Bargadia Ghat	1894	105,000	—	—	—	30·81
									,, Lucknow	1894	114,000	1869	500		
Kali Nadi	—	—	—	Above L. G. Canal Nadrai	2,377	125	2,377	125	,, Nadrai Aqueduct	1885	130,000	—	—	—	55

already mentioned. Small areas of a few square miles of rocky ground which have previously been saturated by slight showers have been known to pass off the entire discharge of a heavy shower within three hours of its fall; while observations on very flat land cultivated with rice in lower Bengal show that the maximum discharge will not exceed one-tenth part of the gross fall on the catchment in any period of twenty-four hours, and that, usually, it is much less.

In dealing with small catchments, say of 100 square miles and less, it is important to remember that, in the plains of India, falls of more than 10 inches in twenty-four hours, although they are occasionally registered, are extremely local in their incidence, and rarely extend over more than a small part of a catchment. On the other hand, there is always a danger of underrating the probable discharge from catchments on which the average annual rainfall is small, on the erroneous supposition that the fall in short periods bears some proportion to the annual fall. On the area commanded by the Chenab Canal in the Punjab, the average annual rainfall is 14 to 15 inches only, but falls of 5 inches in five hours, 6 inches in twelve hours, and 8½ inches in twenty-four hours are recorded in the reports on the canal, and it is stated that at two places (Chenáwán and Shahjamál) the rainfall in a period of six days was 77 and 68 per cent. respectively of the entire average rainfall of the year. When this canal was first opened the drainage crossing it was greatly underestimated, and large additions to the original works had to be made to pass the discharges caused by the heavy falls in short periods. These falls were, in fact, larger than are found in some districts where the annual fall is much greater. Thus, an analysis, extending over a period of thirteen years, of the rainfall affecting an area of rather more than 100 square miles in a part of Bengal where the average annual rainfall is about 60 to 70 inches, showed that, although a fall of 10·87 inches had been recorded in one day, the greatest fall recorded in any period of ten consecutive days had been 13·29 inches: that ordinary heavy falls of rain were those which reached 6 inches in ten days and extraordinary falls of very rare occurrence were those which attained to 10 inches in ten days in June, July, and August, and 13 inches in September and October. It was shown that, on the average of thirteen years, there had been, in each year:—

84·15	days	when the rainfall was less than 1 inch.	
12·47	,,	,, ,,	between 1 and 2 inches.
2·98	,,	,, ,,	,, 2 and 3 ,,
1·0	day	,, ,,	had exceeded 3 inches.

These were facts affecting 100 square miles based on the average of several recording stations: the records of one particular station might give much higher results.

The following data, concerning the flow-off from small catchments, are of some interest. In Lower Bengal, where the rainfall may be 60 to 70 inches in the year, experience has shown that in certain tracts near Calcutta, which are flat and cultivated with rice, a maximum discharge of 6·7 cubic feet per second per square mile (= 0.25 inches in vertical depth over the catchment in twenty-four hours) is sufficient to prevent damage to the crops. Several drainage projects have been carried out on that basis. But the maximum natural flow-off from such areas is about 27 cubic feet per second per square mile. In the Balasore district, close to the coast of the Bay of Bengal, where cyclonic storms occur, a discharge of 112 and 160 cubic feet per second per square mile (4 inches and 6 inches in twenty-four hours off the catchment), and even more have been allowed for in certain works on the Orissa Coast Canal.[1]

A well-authenticated example of the discharge from a small catchment during a cyclonic storm is found in the case of the Red Hills Tank, which supplies drinking water to Madras. The tank has a drainage area of 23 square miles of cultivated land on a moderate slope. The

[1] Note by the Chief Engineer of Bengal, dated February, 1879, on the Orissa Coast Canal.

following figures, which are taken from Colonel O'Connell's[1] report on the cyclone of May, 1877, show the discharges which occurred in this case on an occasion of abnormal rainfall. The rainfall at the Red Hills Tank during the cyclone was—

	Inches.
On 17th May	1·00
„ 18th „	12·03
„ 19th „	4·88
Total	17·91

The rise in the surface of the water during this cyclone was entirely due to the drainage from the catchment basin of 23 square miles, which includes the area of the reservoir itself. The rise and the corresponding drainage are shown in the following table:—

Date.	Level of Water Surface at 6 a.m.	Corresponding Volume in Millions of Cubic Feet.	Daily Difference of Level of Water Surface in Feet.	Additional Volume entering Reservoir.		Drainage in Inches over the Catchment of 23 Miles (including Reservoir).
				Per Day in Millions of Cubic Feet.	Cubic feet per Second.	
May 17th	27·30	253·6886				
„ 18th	30·95	517·0018	3·65	263·3132	3,047	4·92
„ 19th	34·25	838·0862	3·30	321·0844	3,766	6·009
„ 20th	34·79	921·3674	0·74	83·2812	964	1·56

The quantity draining off in the three days amounts to a total of 12·489 inches, which is 69 per cent. of the rainfall. Water continued to run slowly off the catchment basin for nearly a week after the rain had ceased to fall, but the quantity thus discharged did not exceed one-third of an inch, so that the total quantity run off fell short of 13 inches. Taking each day separately, the figures in column 7 for the 18th and 19th of May give coefficients of discharge of 377 and 466 respectively for Ryves' formula $D = C\sqrt[3]{M^2}$, and coefficients of 290 and 359 respectively in Dickens' formula $D = C\sqrt[4]{M^3}$. It is more than probable, however, that these coefficients are too small to represent the maximum discharge, which, especially in the case of cyclonic rain, would doubtless considerably exceed the average discharge from which they are obtained. It has to be borne in mind that this example was recorded in May, when the ground on the catchment was comparatively dry; the run off would have been greater in July or August, when the ground would be damp and not competent to absorb so much of the rainfall. Another observation made on this same tract two years later, in the same month, gave very different results. The rainfall of two consecutive days was 8·75 and 0·50 inches, and of this only 2·00 inches, or 23 per cent. of the total fall, flowed off the catchment into the tank. The difference between the two cases is, no doubt, largely due to the fact that the percentage of flow-off is always very much greater for heavy rain than for comparatively light rain.

In the district of Midnapore, where the annual rainfall is about 50 inches, drainage sluices were constructed with sufficient waterway to carry off 81 cubic feet per second per square mile (= 3·0 inches in twenty-four hours on the catchment) off small areas, but this discharge is now considered very large, and the Surpai sluice, which has been constructed to drain an area of 106 square miles, discharges only 20 cubic feet per second per square mile (=0·75 inches in twenty-four hours) off the catchment.

[1] "Madras Government Proceedings," No. 38, I. of Jan. 14th, 1878.

In Behar, where the rainfall is about 40 inches in the year, it is usual to provide for 40 cubic feet per second per square mile (= 1·5 inches in twenty-four hours) for areas of 10 to 20 square miles, and it has usually been found that 50 cubic feet is a liberal provision.

The following table shows the facts of an unusually heavy flood which occurred on the Beheea Canal in Behar in September, 1903. The discharges were gauged through syphons under the canal and some breaches which occurred in its banks. The discharges given are the maxima, calculated from the highest flood levels: they are not the average. It must not be supposed that the discharge which passed was equivalent to 3·23 inches in twenty-four hours over the catchment: that was the maximum:—

Basin.	Area of Basin.	Rainfall in 48 Hours.	Maximum Discharge from the Basin.	Equivalent Depth over the Basin in 24 Hours.	Cubic Feet per Second.
	Square Miles.	Inches.	Cubic Feet per Second.	Inches.	Cubic Feet.
Behta	39	6·28	3,007	2·95	67
Terari	24	6·28	2,503	3·88	104
Sydaha	29	7·57	2,509	3·22	68
Buchri	17	7·57	1,382	3·02	121
Total...	109	6·89	9,491	3·23	84

The country had a moderate slope, probably 3 feet a mile or so. In September, when the flood occurred, the ground on which the rain fell was thoroughly saturated.

In the Chumparun district of Bengal the average annual rainfall is 50 to 60 inches. The Trebeni Canal runs a few miles from the foot of the hills and is crossed by many drainages. The catchments were divided into "plains" areas, where the surface slope was 4 to 5 feet a mile, and "hill" areas where it was from 6 feet to 15 or 20 feet in a mile. The following table was used in estimating the discharges of the various catchments:—

Area Drained in Square Miles.	Maximum Discharge off the Catchment in Depths in one Hour.	Maximum Discharge in Cubic Feet per Second per Square Mile.
DISCHARGE FROM "HILL" AREAS.		
Less than 4 square miles ...	$\frac{1}{2}$ inch	323
4 to 10 " " ...	$\frac{3}{8}$ "	242
10 to 20 " " ...	$\frac{5}{16}$ "	202
Above 20 " " ...	$\frac{3}{16}$ "	120
DISCHARGE FROM "PLAINS" AREAS.		
Less than 4 square miles ...	$\frac{1}{4}$ inch	161
4 to 10 " " ...	$\frac{5}{16}$ "	120
10 to 20 " " ...	$\frac{1}{8}$ "	80
20 to 100 " " ...	$\frac{5}{32}$ "	60

Numerous drainages cross the main canal of the Periyar[1] Reservoir System in the Madura district of Madras. The slope of the country is steep, being as much as 1 in 150 over wide areas. There are numerous bare hills, and the country is almost devoid of trees and small vegetation.

[1] The Periyar Project, by G. T. Walch, Madras.

Rock is often exposed or only a short distance below the surface. Falls of rain of 1 inch in 15 minutes and 5⅝ inches in twelve hours have been observed. The flow-off is naturally a high one, and the following figures were taken in estimating the maximum discharges:—

Area of Catchment in Square Miles.	Maximum "Flow-off" per Hour in Inches.	Cubic Feet per Second per Square Mile.
0·5	1·20	774
1·0	0·93	600
2·0	0·74	477
3·0	0·65	420
5·0	0·54	348
10·0	0·43	277
18·0	0·35	225
25·0	0·31	200
75·0	0·22	142

In the United Provinces the data given in the following table were adopted[1] for determining the waterway to be provided in passing drainage under canals and distributaries in a tract where the average annual rainfall is about 32 inches:—

Area of Tract Drained in Square Miles	Discharges to be Allowed for.	
	Cubic Feet per Second per Square Mile.	Equivalent Depth in 24 Hours over the Catchment in Inches.
From 1 to 10	80	3·0
" 10 " 20	56	2·0
" 20 " 50	32	1·2
" 50 " 100	26	0·9
" 100 " 500	22	0·8
" 500 " 1,000	18	0·6
" 1,000 " 2,000	16	0·5
" 2,000 " 3,000	12	0·4

The experience of the Kali Nadi Aqueduct[2] has shown that this table does not allow for nearly sufficient discharge from the larger areas. In the case of certain drainages affecting the Jhelum Canal project in the Punjab, 35 cubic feet per second per square mile was the maximum flow-off which was originally provided for: the rain varying from 8 to 22 inches in the year, but falls of 6 inches in one day—or even in as many hours—have been recorded, and the original provision was insufficient. In the district of Sarun in Bengal drainage sluices in the embankments are designed to permit of a discharge of 100 cubic feet per second per square mile; but this is believed to be excessive.

These examples refer to catchments of agricultural land in the plains, in which the general slope of the country concerned might vary from 6 inches to 3 or 4 feet in the mile, and where the maximum daily rainfall would rarely exceed 4 inches, although it would at times, and in restricted areas, reach to 10 or 12 inches.[3]

[1] "Report on the Project of the Lower Ganges Canal," dated November, 1870.
[2] See page 51.
[3] Even 20 inches has been recorded in extremely abnormal cases.

The maximum discharge which may be expected from small catchments in rocky and hilly ground are much larger. The waterway allowed on hill streams crossing the East Indian Railway at Rajmehal is sufficient to carry off 350 cubic feet per second per square mile. Sir Proby Cautley allowed 323 cubic feet (12 inches in twenty-four hours over the catchment) on hill streams in the Sewalics. In the case of a tank at Satara, which has a catchment of less than 3 square miles of rocky ground, the waste weir has been constructed to carry off a depth of 3 inches off the entire catchment in one hour, or 1,936 cubic feet a second per square mile. The waste weir of the tank at Jubbulpore, which supplies the waterworks of that city from a catchment of 5¼ square miles of rocky ground, has been constructed to carry off 5·44 inches in one hour off the catchment, which is equivalent to the enormous (and probably excessive) discharge of 3,514 cubic feet a second per square mile, although the maximum rainfall recorded in twenty-four hours was only 12·49 inches. Another instance in which an excessive discharge appears to have been allowed for is mentioned on page 239. The waste weir of the tank which supplies the waterworks of Nagpur in the Central Provinces, which has a catchment area of 6·6 square miles of low basalt hills, has a maximum discharge of 967 cubic feet a second per square mile, which is equivalent to a depth of 1·5 inches over the catchment in one hour. In these cases, where the slope is very rapid, it is necessary to base the calculations of flow-off not on the daily rainfall, but on the hourly rainfall. The following table and the one on the next page give some interesting statistics concerning the flow off the catchment of the Nagpur tank which has just been mentioned:—

NAGPUR WATERWORKS.—TABLE OF EXTRAORDINARY SHOWERS DURING THE MONSOON OF 1872.[1]

Date.	Rainfall.			Rise of Reservoir in Feet.	Duration of Rise.		Rate of Flow in Cubic Feet per Second per Square Mile	Proportion of the entire Rainfall of each Shower which flowed off the Catchment during the Period of Rise.
	Fall in Inches.	Duration of Fall.						
		Hours	Min.		Hours	Min		
June 18th	2·24	1	20	Unimportant			*Nil*	—
July 3rd	3·92	24	—	1·50	24	—	16	0·16
„ 10th	0·71	—	20	0·32	3	—	61	0·204
„ 12th	1·26	—	30	1·00	3	—	106	0·392
August 9th	0·97	1	30	0·10	2	—	20	0·065
„ 10th	3·50	1	45	3·15	3	—	457	0·607
„ 24th	1·00	—	40	0·60	3	—	109	0·510
September 7th ...	0·60	1	0	0·60	5	30	65	0·940
„ 16th ..	0·50	—	30	0·40	6	—	41	0·760
	2·20	1	20	2·20	2	50	492	0·983
October 6th	0·50	—	20	1·34	3	0	439	0·346
	3·55	—	45					

The most striking fact displayed by these tables is the enormous effect produced on the discharge by the condition of the catchment area at the time of the fall. The fall of 2·24 inches falling in eighty minutes in June when the catchment area was perfectly dry and baked by the previous hot weather, only raised the reservoir by the amount due to the actual depth of the fall on the waterspread: there was no discharge from the catchment, and during the whole month of June less than one-fiftieth part of the gross rainfall on the ground flowed into the reservoir: while on the 16th of September, when the catchment was

[1] Taken from Report No. 27 on the Nagpur Waterworks, dated Feb. 28th, 1873, by Mr. (now Sir) A. R. Binnie.

thoroughly saturated by the rain which had fallen on fifty-five days out of the previous eighty-nine, a shower of 2·20 inches falling in eighty minutes produced a discharge into the reservoir of no less than 98 per cent. of the entire fall on the ground draining into it within a period of three hours, and the flow-off of the whole month was equivalent to 72 per cent. of the entire rainfall of the month.

NAGPUR WATERWORKS.—TABLE SHOWING THE MONTHLY FLOW-OFF DURING THE RAINS OF 1872.

Month.	Rainfall of Each Month.	Total Rise in Reservoir During each Month.	Quantity of Water Received in the Reservoir.		Proportion of the Rainfall of the Month Impounded in the Reservoir.	
			From the Rainfall on the Actual Water Surface.	From the Water Flowing off the Ground.	From the whole Catchment Area including Water-spread.	From the Water Flowing off the Ground only.
	Inches.	Feet.	Millions of Cubic Feet.	Millions of Cubic Feet.		
June	6·77	0·83	2·996	1·888	0·047	0·018
July	12·70	5·72	8·100	36·296	0·227	0·194
August ...	11·82	8·55	11·465	89·670	0·558	0·529
September ...	7·99	4·90	9·551	81·645	0·744	0·724
October ...	4·37	1·55	5·630	20·800	0·394	0·338

In such small tracts as those referred to in these examples, falls of even 5 inches in an hour may be expected, and it is necessary to make provision for escaping a large proportion of such a fall (probably from one-fourth to two-thirds), according to the slope of the catchment area.

The following statement shows the capacity of the waste weirs on tanks and reservoirs in the Bombay Presidency situated on rivers and streams in hilly ground :—

Number of Tanks on which Statistics are based.	Average Annual Rainfall.	Area of Catchment.	Slope of the River above the Reservoir.	Maximum Discharge for which the Waste Weir is Designed.
	Inches.	Square Miles.	Feet per Mile.	Cubic Feet per Second per Square Mile
6	from 15 to 30	less than 10	30 to 40	from 528 to 967
10	,, 21 ,, 30	from 10 to 50	17 ,, 41	,, 645 ,, 860
7	,, 23 ,, 40	,, 50 ,, 100	12 ,, 29	,, 438 ,, 645
7	,, 23 ,, 55	,, 100 ,, 600	4½ ,, 12	,, 212 ,, 645

The statement shows how great are the discharges which may be obtained in tracts where the annual rainfall is slight.

Mr. Strange[1] gives the table on the next page as a rough approximation to the discharge that may be expected from various depths of rainfall on an ordinary drainage area in the Deccan. The statement shows clearly the important effect which the condition of the catchment has on the flow-off.

In dealing with projects which require an estimate of the maximum flow off a catchment, it is always the best plan, where it is possible, to base the estimate on the discharges recorded in the streams which actually drain the area. It is often possible to ascertain approximately

[1] "Indian Storage Reservoirs," by Mr. W. L. Strange.

the highest flood levels and to arrive at the surface slope of the stream: this information, with cross sections of the stream, will afford better grounds for an estimate than can be obtained from formulæ applied to the area of the catchment.

Rainfall in 24 Hours.	Condition of the Catchment at the Time of the Rainfall.		
	Dry.	Damp.	Wet.
	Percentage of Flow-off.	Percentage of Flow-off	Percentage of Flow-off.
$\frac{1}{4}$ in.	*Nil.*	*Nil.*	12
$\frac{1}{2}$ in.	—	10	14
1 in.	5	14	20
2 in.	10	25	34
3 in.	20	40	55
4 in. and over	30—40	50—60	70—80

The maximum discharge from a catchment, during any short period, is important with reference to the bye-wash, or waste weir, of a reservoir or tank, but it is essential to ascertain the average (or minimum) flow-off during a longer period (or during the period when water can be impounded), in order to know what quantity of water will be stored for irrigation. In considering this problem, which is one of great complexity, an analysis of the rainfall for a series of years is desirable in order to ascertain the rainfall which can be expected under the most unfavourable circumstances; for, as a rule (which is subject to exceptions) the financial success of a reservoir project will depend largely on its efficiency under those conditions. The diagram shows such an analysis of the reservoir rainfall at Jubbulpore in the Central Provinces for thirty-five years.

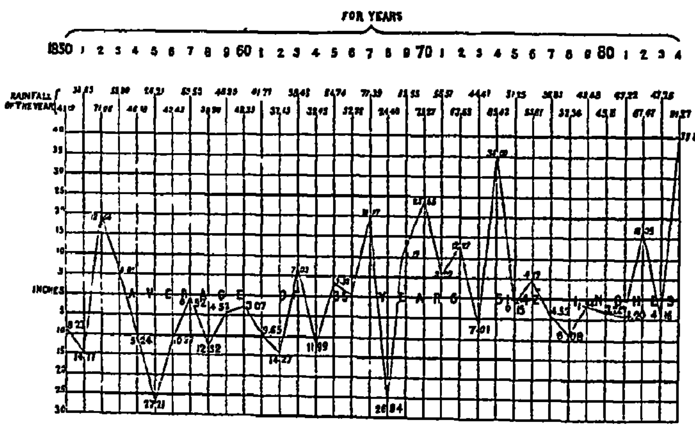


DIAGRAM OF MONSOON RAINFALL AT JUBBULPORE.

The figures in the body of the diagram show the number of inches which the rainfall of the year was greater or less than the average of thirty-five years. Thus the fall in 1882 was 16·05 inches greater, and that of 1883 was 4·16 inches less than the average. A study of this diagram shows that—

The maximum rainfall of any one year (1884) was	91·27 inches.
The minimum ,, ,, ,, (1885) ,, ...	24·21 ,,
Greatest number of consecutive years in which the rainfall was below the average was	9 years
The average fall during these nine years was	41·60 inches
The average fall of the three driest consecutive years was	36·94 ,,

Observations recorded both at Nagpur and at Jubbulpore showed that, in ordinary years, the gross flow-off from a rocky catchment of 5 or 6 square miles in area was 40 per cent. of the entire rainfall. In the Bombay Presidency, where there are many tanks and reservoirs, having

catchments varying from 3 to 600 square miles in area, it is generally assumed that 25 per cent. only of the total rainfall (which is generally about 20 to 25 inches in the year) is impounded in the reservoir. But the gross flow-off in years of exceptionally low rainfall bears a smaller proportion to the rainfall than that of ordinary years; so that, if it is considered necessary to base the calculations on the minimum probable supply, as little as 10·0 per cent. of the rainfall of the year has to be taken. The following examples of actual results are interesting.

In the Oopahalli tank at Bangalore in Mysore (an exceptionally bad case) the gross flow off the catchment during six years varied from 10·0 to 19·0 per cent. only of the gross rainfall on the catchment. In the Hulsar tank at Bangalore the average flow-off of three years was only 14·0 per cent. of the total rainfall.

In Rajputana it is commonly assumed that one-tenth of the rainfall of the year will reach a reservoir from its catchment area. It is usually found that this figure errs on the safe side. In Marwar, however, where the rainfall in ordinary years is from 12 to 18 inches, the flow-off hardly ever exceeds one-thirtieth of the rainfall; the soil is sandy, and the rainfall, as a rule, is light. Instances are on record in Rajputana where large reservoirs, which in some years do not fill to half their capacity, have been filled in a single day by the only fall of any importance which occurred during the year.

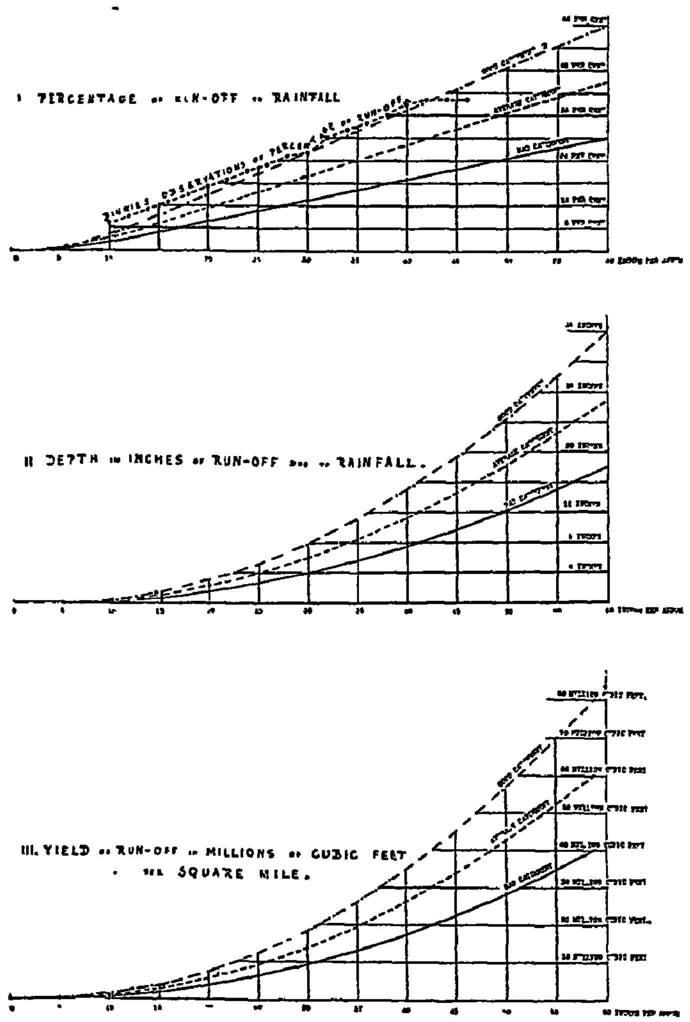
The Bombay Government published in the Administration Report of the Public Works Department (1890—91) a statement showing the results of run-off from the catchment areas of tanks in the Deccan. The statement dealt with observations recorded on nineteen tanks, and was based, as a rule, on the available monsoon rainfall, which was generally about 20 to 30 inches, but fell in some cases to as little as 4 or 5 inches. The statement showed that out of these 114 observations there were—

26 occasions when the flow-off was	less than 10	per cent. of the available rainfall.
44 " " " "	between 10 and 20	
25 " " " "	" 20 and 30	
19 " " " "	above 30	

The following facts are taken from the Bombay Irrigation Revenue Reports: the reservoirs mentioned are three of the best in the Bombay Presidency:—

Year.	Mashvad Tank. Catchment 484 Square Miles.			Ashti Tank. Catchment 92 Square Miles.			Ekruk Tank. Catchment 159 Square Miles.		
	Rainfall in the Monsoon Months in Inches.	Percentage of Total Flow-off to Rainfall.	Percentage of Loss in Twelve Months by Evaporation and Absorption in the Reservoir.	Rainfall in the Monsoon Months in Inches.	Percentage of Total Flow-off to Rainfall.	Percentage of Loss in Twelve Months by Evaporation and Absorption in the Reservoir.	Rainfall in the Monsoon Months in Inches.	Percentage of Total Flow-off to Rainfall.	Percentage of Loss in Twelve Months by Evaporation and Absorption in the Reservoir.
1895-96	23·99	14	37	30·65	40	62	35·36	48	27
1896-97	11·45	19	45	11·80	14	55	16·89	10	44
1897-98	21·45	38	13	41·09	43	28	27·59	32	27
1898-99	16·05	20	18	18·95	11	26	29·28	13	22
1899-00	8·77	19	25	12·05	21	52	12·50	4	25
1900-01	11·03	15	10	14·47	7	21	15·34	10	26

It must be remembered that the rainfall is that of the five monsoon months and not that of the whole year, which would be about 10 per cent. greater. It is the fall of the monsoon months alone which supplies the reservoirs. It will be seen that, in the cases where 30 to 40 inches of rain falls in five months, 40 per cent. of the rainfall has been impounded. But the percentage is, as a rule, very much smaller when the rainfall is less. The statement displays the fact that the percentage of flow-off does not vary with the annual rainfall. This is a common experience, as the following examples show. In the case of the reservoir[1] of the Baroda Waterworks, which has a catchment area of 36 square miles, 30 per cent. of the rainfall was impounded in one year; but in another the flow-off was only 13 per cent., although, in the latter case, the total rainfall of the year was slightly the greater of the two. In Jeypore,[2] with a rainfall of about 24 inches in the year, a reservoir was constructed in the hopes that one-sixth of the annual fall would be impounded. But experience has proved that only one-sixtieth part is stored. The enormous variation in the volume which may be obtained from a catchment is well illustrated by the results of thirteen years' observations on the Sweet Water Reservoir[3] in California. The reservoir has a catchment of 186 square miles, ranging from 220 to 5,500 feet above the sea. The rainfall, at the site of the dam, averages about 9 inches only, but varies from nothing up to 16½ inches. In 1894—95 the flow-off was half the rainfall: in 1889-90 a larger rainfall gave a flow-off of one-eighth only; the best three years gave a flow-off of one-sixth; the worst years gave none at all. The average of thirteen years, including the abnormal year 1894—95 gave a flow-off of one-fifth the rainfall, but, excluding that year, the proportion was one-tenth only. In the case of the great Marikanave Reservoir in Mysore it is estimated that there will be a flow-off of—



DIAGRAMS SHOWING APPROXIMATE RUN-OFF FOR VARIOUS RAINFALLS.

$\frac{1}{9}$th of the gross rainfall in a bad year of				15 inches of rainfall.	
$\frac{1}{7}$th	,,	,,	,, an average year of	24 ,,	,,
$\frac{1}{6}$th	,,	,,	,, a good year of	30 ,,	,,

This reservoir (page 77) has a catchment area of 2,075 square miles. The estimate seems to be a high one. All the facts prove clearly the great uncertainty of the prospects of any reservoir scheme which depends entirely on the rainfall on a given catchment.

[1] Page 49, vol. cxv. Proc. Inst. of C.E. [2] Page 56, same volume. [3] Page 149 of "Schuyler on Reservoirs."

Mr. W. L. Strange gives, in his book on Indian Storage Reservoirs, a table and diagram of discharges which he considers generally suitable to bad, average, and good catchments respectively. The diagrams on the opposite page are taken from those given in the book.

The following facts are recorded in the report[1] of the Rushikulya project in Madras:—

Year.	Mahanadi. Catchment 900 Square Miles.		Rushikulya. Catchment 850 Square Miles.	
	Rainfall of the Year in Inches.	Percentage of Total Flow-off to Rainfall	Rainfall of the Year in Inches.	Percentage of Total Flow-off to Rainfall.
1868	44·1	5·0	44·1	6·3
1869	59·6	36·1	59·6	31·0
1870	55·5	51·3	52·7	74·2
1871	43·7	18·0	42·0	8·4

These facts show, generally, that the percentage of flow-off does decrease with the total annual rainfall, but that the same annual rainfall does not produce the same percentage of flow-off. This is because the rainfall is not distributed in the same way during the period of its fall. Thus, if in two years having the same total fall during the monsoon, the fall in one year is chiefly in June and July and in the other year is chiefly in August and September, the total flow-off will be greater in the second year, because the discharge from saturated land is far greater than that from dry land. Or if, in two such years, the fall of one year is equally distributed in gentle showers during the season, and, in the other year, the same total fall is recorded mainly in heavy falls lasting a short time, the flow-off will be far greater in the latter case, especially if the heavy falls occur when the catchment is damp. It follows from this that an estimate of flow-off, to be accurate, must be based on an analysis of the monthly falls, or even on falls during shorter periods than that. The table on page 60 gives such an analysis for a certain tract. The following results were obtained[2] from an investigation of the rainfall on a catchment of about 100 square miles near Calcutta:—

Month.	Percentage of the Rainfall Flowing off the Catchment during the Month.	
	In Years of Ordinary Rainfall during the Month.	In Years of more than Ordinary Falls during the Month.
June	5·0	10·0
July	10·0	20·0
August ...	25·0	50·0
September ...	40·0	50·0
October ...	40·0	50·0

In all tanks and reservoirs there is a loss of water from leakage, absorption into the soil, and evaporation, which varies from as much as 10 feet in vertical depth of water annually to as

[1] Dated March 8th, 1882, by Mr. C. Vincent, Ex. Engineer. [2] By the author.

little as 3 feet. In some cases there is a compensation for this loss in springs in the bed of the tank. The total actual loss from these causes has been measured in many instances, but it is always difficult to ascertain how much of it is due to each of the causes of loss. The loss from evaporation alone is believed never to exceed 0·4 inches a day in the hottest and driest weather in India. The loss from absorption varies greatly, according to the nature of the bed of the reservoir, but it may generally be taken at not more than half the loss by evaporation during the year, although, in the earlier months of the period when the flow off the catchment is being impounded, it would be much greater; the loss by leakage depends entirely on local circumstances, and is generally very small. The following statistics of the loss in different cases may be of use.

The loss by evaporation and absorption (which was probably very small) in the Red Hill Tank at Madras, which has a water surface of 5 to 6 square miles, was gauged during a period of five years, with the result that the average daily loss of that period was found to be 0·28 inches. The average[1] daily loss based on the facts of—

	Inches.		Inches.
4 Januaries was	0·24	4 Julys was	0·33
2 Februaries „	0·24	5 Augusts „	0·32
5 Marches „	0·26	1 September „	0·38
5 Aprils „	0·30	1 October „	0·27
5 Mays „	0·37	1 November „	0·27
4 Junes „	0·30	2 Decembers „	0·13

The figures give results which are higher than would have been expected.

In the Ekruk Tank in Sholapore, Bombay, having a water spread of about 7 square miles, the loss from evaporation and absorption during the hottest part of the year (April 17th to May 29th) was found to average 0·384 inches a day, while the loss from the same causes, but with the addition of some leakage, during November to March, averaged 0·232 inches a day.

The loss in tanks in Rajputana is given by Mr. W. W. Culcheth as follows:—

1. Loss by evaporation and absorption in porous soils:—

Season.	Average Daily Loss in Inches from—		
	Evaporation.	Absorption.	Total.
During the Irrigating Season, October to March	0·15	0·15	0·20
„ Hot „ April to June	0·29	0·17	0·56
„ Rainy „ July to September	0·21	0·20	0·41
Average of the year	0·20	0·12	0·32

These results are equivalent to a total vertical loss in the year from the surface of the tank of 6·15 feet from evaporation, 3·62 feet from absorption, or 9·77 feet in all.

2. The loss from absorption in porous soils is probably two-thirds of that from evaporation, but is reduced by springs to one-half.

3. When water is impounded in the monsoon months and drawn off for irrigation by the end of March the total vertical loss may be taken as 3 feet.

[1] "Monograph on the Madras Water Supply and Irrigation Extension Project," by Mr. C. Vincent.

In the Pashan tank, near Poona, the average daily loss from evaporation alone has been gauged as 0·25 inches in October; 0·19 in November; 0·14 in December; 0·17 in January; 0·14 in February; 0·17 in March; 0·27 in April; 0·38 in May.

In the Nagpur Reservoir in the Central Provinces the maximum loss recorded from evaporation and absorption in one day was 0·60 inches, and the average loss from both causes during the 142 days from October 10th to June 9th (that is, the period of the year when the monsoon is absent) was 0·347 inches a day—the loss from evaporation alone being estimated to be 0·20 inches.

Observations made in the water supply reservoir in Bangalore show that the maximum loss from evaporation and absorption is about $\frac{3}{8}$ inch a day in February, March, April and May, and that it varies from $\frac{1}{4}$ inch to $\frac{3}{8}$ inch during these four months; the total loss in those months and during the first fifteen days of June being about 4 feet. During the other seven and a half months of the year the loss is about 1 to $1\frac{1}{2}$ feet, but, in exceptionally dry and windy years, it is as much as 2 feet. In the majority of the Mysore tanks the loss is assumed to be 6 feet in the year; they are mostly comparatively shallow tanks.

The Foy Sagar Reservoir[1] in Ajmer has a capacity of 150 millions of cubic feet. The following table was prepared by the Executive Engineer:—

Season.	Vertical Loss in Feet from the Surface of the Tank.								
	1895—1896.			1896—1897.			1897—1898		
	Evaporation.	Percolation and Absorption.	Total.	Evaporation.	Percolation and Absorption.	Total.	Evaporation.	Percolation and Absorption	Total.
October to March ...	2·93	0·70	3·63	2·73	0·83	3·56	2·58	0·69	3·27
April to June	3·26	0·42	3·68	3·40	0·39	3·79	3·41	0·31	3·72
July to September ...	1·17	0·61	1·78	0·79	0·61	1·40	1·45	0·56	2·01
Total for the Year...	7·36	1·73	9·09	6·92	1·83	8·75	7·44	1·56	9·00

The loss in the period October to June is the most important, and in the succeeding years the loss in the rains (July to September) is not recorded. The total loss in this tank from October to June from evaporation, percolation, and absorption has been:—

	Vertical Feet.		Vertical Feet.
1895—1896	7·31	1900—1901	(?)
1896—1897	7·35	1901—1902	5·38
1897—1898	6·99	1902—1903	5·99
1899—1900	7·35	1903—1904	5·76

During the five years 1899—1904 the average daily loss from October to March was 0·20 inches in vertical depth, and from April to June it was 0·40 inches.

In the Bareta Bund[2] in Bharatpur, a tank having a capacity of 1,360 millions of cubic feet, a record is kept of the daily fluctuations of water level. The table on the next page shows the

[1] Note by Mr. Manners Smith, dated December 7th, 1904.
[2] Statement by Mr. H. F. D. Burke, State Engineer, Bharatpur.

loss from all sources during certain months when all the channels were closed and when there was no rainfall :—

Month.	Average Daily Loss in Inches.	Month.	Average Daily Loss in Inches.
August, 1899 ...	0·77	May, 1902 ...	0·50
October, 1899 ...	0·79	October, 1902 ...	0·45
December, 1899 ...	0·72	October, 1903 ...	0·43
January, 1900 ...	0·72	March, 1904 ...	0·33
May, 1900 ...	0·72	October, 1904 ...	0·43

The losses are very high, and it would appear that the percolation must have been heavy. The case illustrates an extreme example. The vertical loss is between 13 and 14 feet in nine months. In this particular tank the amount lost by evaporation, absorption, and percolation, in a period of six years, actually exceeded that used in irrigation.

In the very dry climate of Upper Egypt the evaporation during the hottest months has been very carefully estimated to be 0·39 inches a day.

The quantity of water which is lost by absorption can be determined by no rule; it varies both with the nature of the soil on which a tank is constructed, or in which a canal is cut, and with the spring level of the subsoil. The loss is greater in running canals than in reservoirs. Mr. J. S. Beresford, who studied the matter closely in the North-West Provinces, came to the following conclusions :—

1. That loss by absorption is greater when a canal is in cutting than when it is in embankment.

2. That, when the other conditions are constant, the loss by absorption varies directly as the wetted perimeter of the channel.

3. That under ordinary conditions the loss by absorption between the head of a distributary and any point L miles from the head can be approximately ascertained by the formula

$$\text{Loss} = A\,L^x,$$

where A is the loss actually ascertained by experiment in the first mile, and x, the power to which L is raised, varies from $\frac{5}{6}$ to $\frac{6}{7}$.

4. That there is more waste by absorption in village channels than in all other parts of an irrigation system.

The loss by absorption is much greater, as a rule, in new canals than in old ones, as the porous surface of an absorbent soil becomes staunched by the silt which is deposited on it and drawn into the interstices of the ground. This is of course more particularly the case when the water of the canal is much charged with silt, and will not occur when the canal carries clear water.

The extent to which this staunching action of the silt may be carried is well illustrated by the filters of the Calcutta Waterworks. The water is pumped from the Hoogly, which at times carries a large percentage of fine muddy silt, and is settled for four or five days in large settling tanks before it is passed, in a comparatively clear state, on to the filters which are constructed of layers of pebbles, gravel, coarse sand and fine sand in layers, the fine sand being on the top. At those times when there is much silt in the river these filters become so far choked with silt as to be almost water-tight against a head of 24 inches or so, and this staunching is almost

entirely effected in the topmost half inch of the fine sand. When this half inch is removed, every fortnight or so, the filters again become efficient. The same action goes on in a canal, and, so far as may be, it is desirable to let the silt remain untouched in canals and distributaries where absorption is likely to occur.

The extent to which absorption may reduce the discharge of a canal is rarely appreciated. A small canal, called the Hathmati canal, in Bombay, carrying an ordinary discharge varying from 20 to 100, and a maximum discharge of 191 cubic feet a second, has been gauged[1] for a series of years, and the results show that at least 50 per cent. of the discharge is lost by evaporation and absorption in the first 10 miles, in which there is practically no irrigation. This is an extreme case, but losses of from 10 to 40 per cent. between the head of an irrigation system and the fields actually watered are to be expected. On a sandy reach of the Patna Canal in Bengal, an exceptional opportunity once occurred for gauging the actual loss by absorption. The canal was new, the reach was 7 miles long, 69 feet base, and had about $4\frac{1}{2}$ feet of water at one end, and 8 at the other (the water being impounded): the loss by absorption was found to be over 40 cubic feet a second. This has now been greatly reduced by silt deposited on the bed and banks of the canal.

The Nira Canal, near Poona in Bombay, has a total length of 100 miles, and has a head discharge of 455 cubic feet. Careful experiments[2] have shown that the average loss in the canal from evaporation, absorption, and percolation amounts to 1 cubic foot per second per mile, or 100 cubic feet per second altogether, which is 22 per cent. of the maximum discharge entering at the head. The results obtained for the loss by leakage in this canal, correspond very closely with those on the Mutha Canal in the same district, where the loss was found to be from 0·8 to 0·9 cubic feet per second per mile, the maximum head discharge being 412 cubic feet.

Some experiments were recorded[3] by Mr. Higham on the Bari Doab Canal in the Punjab, after it had been open for some sixteen or eighteen years, to determine the loss due to evaporation and absorption. Care was taken to get the canal into train, and to shut off all distributary heads and other sources of leakage. The first series of observations was made on the upper portions of the canal, 52 miles in length, between Madhopur and Chandeki, which runs in a light boulder soil. The velocities were carefully ascertained by suitable floats. The results were :—

Experiment.	Date.	Madhopur.		Chandeki.		Loss.	
		Mean Velocity.	Discharge.	Mean Velocity.	Discharge.	Volume.	Percentage
		Feet per Second.	Cubic Feet per Second.	Feet per Second.	Cubic Feet per Second.	Cubic Feet per Second.	
A	March 1 and 2	—	2,009	2·68	1,728	281	14·0
B	May 26 and 27	4·44	2,142	2·93	1,874	268	12·5
C	May 28 and 29	4·33	2,036	2·79	1,789	247	12·1
I	June 9 and 10	4·44	2,165	2·77	1,874	291	13·5

[1] "Bombay Revenue Report," 1889—90.
[2] "Report on the Nira Canal Project," published by the Government of Bombay, 1892, page 12.
[3] Report dated December 7th, 1875.

The second series of observations was made lower down the canal between Hibban and Gandian, a length of 63 miles, where the canal is in stiff soil. The results were:—

Date	Hibban.	Gandian.	Loss.	
	Discharge in Cubic Feet per Second.	Discharge in Cubic Feet per Second	Cubic Feet per Second.	Percentage.
July 31st ...	289·4	243·2	46·2	15·9
August 2nd ...	384·3	298·4	85·9	22·4

At the same time observations which were recorded on two or three distributaries showed a percentage of loss, in those channels, varying from 20 to 30 per cent. of their discharges at head. These results, it should be remembered, were not on a new canal, but on one which had been so long in operation that all abnormal causes of loss had been removed. They are of great importance with reference to the extent of country which can be irrigated with a given supply of water and bear materially on the matter of the "duty" of water for irrigation, which will be treated in Chapter XV.

Mr. J. H. Ivens made some experiments on the Ganges Canal, between the head at Hardwar and its bifurcation into the Cawnpore and Etawah branches. In this length of 181 miles he found the loss in winter to be 13·2 per cent. and in summer 15·6 per cent. of the volume entering at Hardwar. He found the loss in village watercourses varied from 0·21 to 0·67 per cent. per mile. This was in fairly well puddled channels when silt had been deposited on the sides and bed. Mr. Ivens gives the following figures as generally applicable to an entire canal system in the United Provinces. Of each 100 cubic feet per second entering the canal:—

15 cubic feet are lost in the canal.
7 " " " distributaries.
22 " " " village watercourses.

Fifty-six cubic feet only are actually used in the fields, and 27 feet out of this 56 are held to be really wasted by the cultivators, one way and another, but mainly in excessive irrigation. Experiments[1] made in the Bari Doab Canal in the Punjab showed that in the *rabi* season of 1881—82 out of every 100 cubic feet entering the head of the canal, 20 cubic feet were lost in the canal proper, 6 cubic feet in distributaries, and 21 cubic feet in village watercourses. This left 53 cubic feet delivered on the fields, of which it was estimated that 25 cubic feet were wasted in various ways. These figures agree very well with those just given for the Ganges Canal. With reference to the waste of 27 cubic feet in the one case and 25 cubic feet in the other, it must be remembered that these figures are, more or less, estimates of the amount used in excess of the actual requirements of the plants. It is perhaps hardly fair to conclude that water is wasted because, judged by some standards, it is in excess of the quantity absolutely required by the plants in the field. There can be little doubt that the volume of water delivered on a field is always considerably in excess of that necessary for the plants, if it were possible to treat each individual plant separately; but it is not possible.

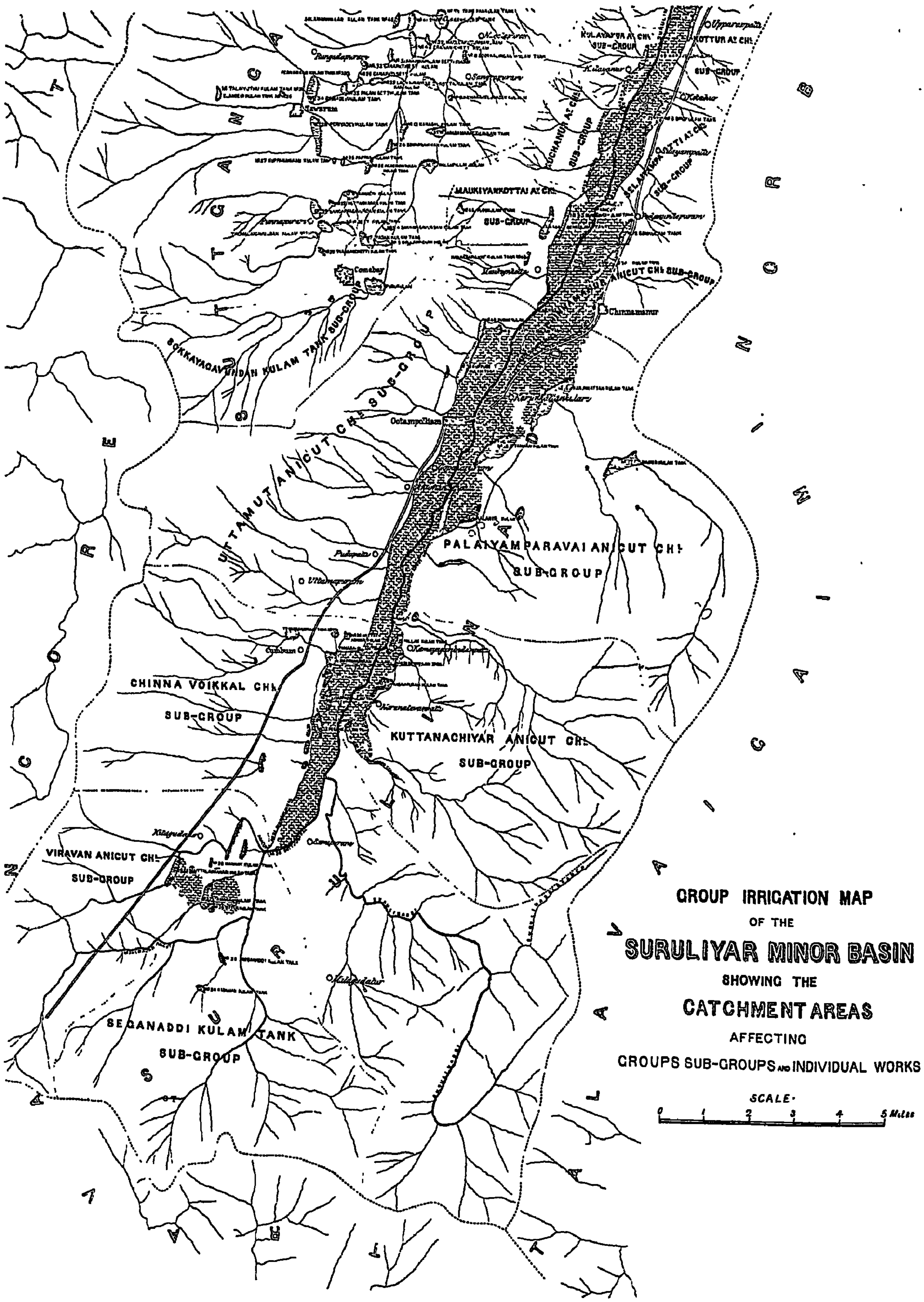
In the Punjab[2] it is usual to allow 8 cubic feet per second per million square feet of wetted

[1] "Note on Irrigating Duty of the Bari Doab Canal," by Mr. R. G. Kennedy, 1883.
[2] Page 27 of Mr. Benton's Report on the Project for the Upper Jhelum, Upper Chenab, and Lower Bari Doab Canals.

area of the channels, for the loss by absorption. The following table shows what this loss amounts to on some of the great canals. The first three canals are open, the second three are about to be constructed:—

Canal.	Area of *Rabi* Irrigation.	Mileage of Main Canals and Branches.	Wetted Area of the Channels.	Loss in the Channels.
	Acres.	Miles.	Millions of Square Feet.	Cubic Feet per Second.
Upper Bari Doab	442,300	353	82	820
Lower Chenab	1,155,700	426	204	1,632
Lower Jhelum	383,100	180	78	624
Upper Jhelum	172,500	136	83	664
Upper Chenab	324,200	194	145	1,161
Lower Bari Doab	441,300	196	121	965

The figures in the last column show how very great the losses of water are on these large canals; it amounts to 25 or 30 per cent. between the head-works of the canals and the heads of the distributaries taking off the main and branch canals.


GROUP IRRIGATION MAP
OF THE
SURULIYAR MINOR BASIN
SHOWING THE
CATCHMENT AREAS
AFFECTING
GROUPS SUB-GROUPS AND INDIVIDUAL WORKS
SCALE
0 1 2 3 4 5 Miles
UTTAMUTANICUT CH. SUB-GROUP
PALAIYAMPARAVAI ANICUT CH. SUB-GROUP
CHINNA VOIKKAL CH. SUB-GROUP
KUTTANACHIYAR ANICUT CH. SUB-GROUP
VIRAVAN ANICUT CH. SUB-GROUP
SEGANADDI KULAM TANK SUB-GROUP
SOKKAYAGAVUNDAN KULAM TANK SUB-GROUP
MAUKIYANKOTTAI AT CH. SUB-GROUP
KOTTUR AT CH. SUB-GROUP
Cumbum
Chinnamanur
Comebay

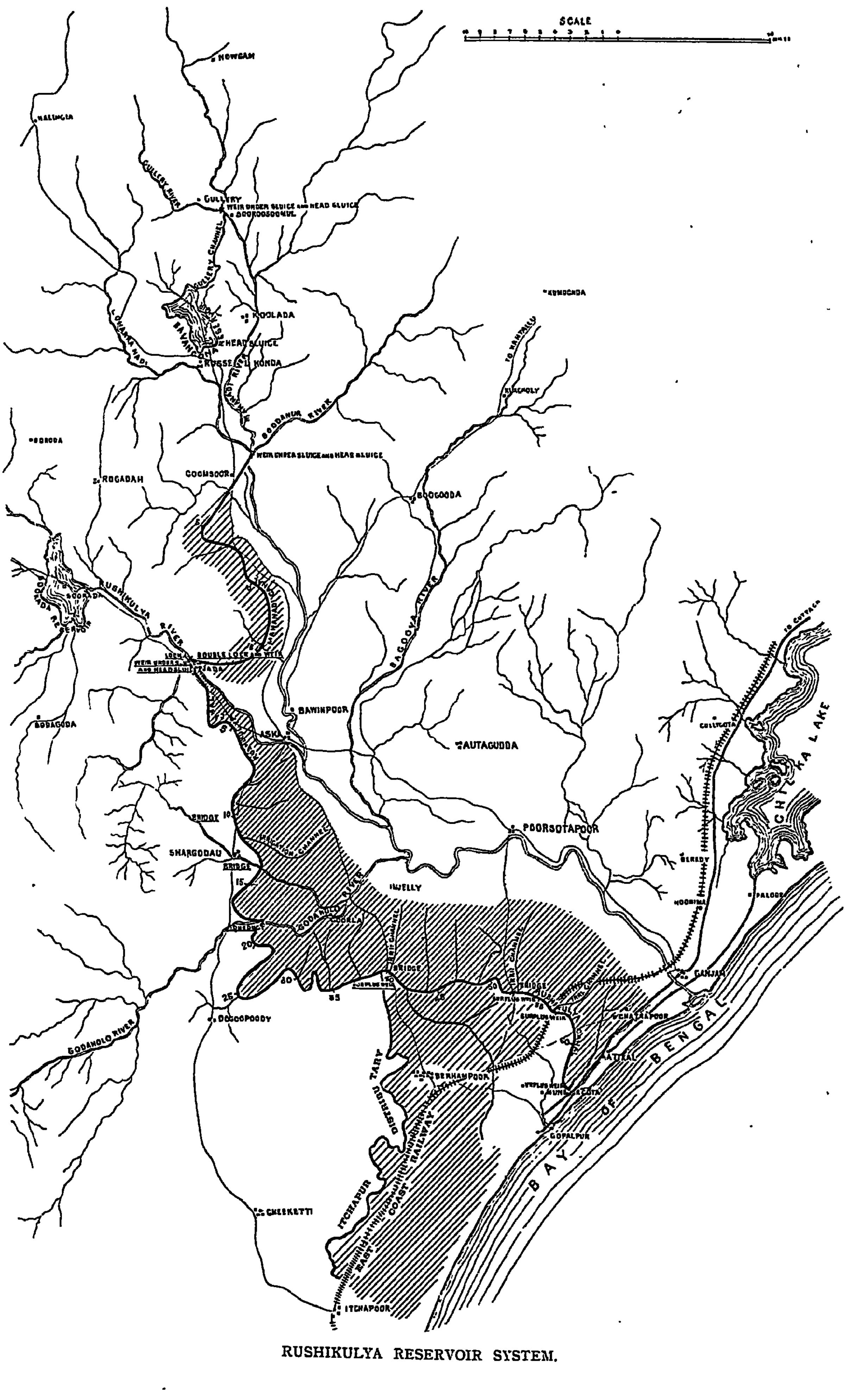
CHAPTER V.

STORAGE WORKS, RESERVOIRS, TANKS.

Madras Tanks—Rushikulya Project—Periyar Project—Cross Sections of Various High Masonry Dams—Marakinave Reservoir—Nira and Mutha Canals—Bhatgarh Reservoir—Conditions of Design of Bhatgarh Dam—Weight of Concrete in Bhatgarh Dam—Under-sluices of Bhatgarh Dam—Waste Weirs of the Bhatgarh Reservoir—Head-works of the Nira Canal—Tanks in Rajputana—Earthen Embankments—Grass Revetments in Tanjore—Statistics of the Principal Tanks in Bombay—Statistics of Rajputana Tanks.

MADRAS and Bombay are the two provinces of India in which the demand for the storage of water is most apparent. In both cases the majority of the rivers have short courses, and the rainfall, which frequently falls in heavy but brief storms, passes rapidly away. The waters of the larger Madras streams have been partially utilised in irrigating their deltas on the coast by large perennial irrigation canals. In the higher ground, where such works are unsuitable, the water of the smaller streams is economised in a vast number of tanks, which are dotted about all over the face of the country. These tanks are being extended and improved by Government. The following description has been taken from the book of estimates and plans for these improvements.[1] The country is divided into "basins" and "minor basins," according to the catchment areas of the streams and the tanks situated in them: the tanks are divided into groups and sub-groups for statistical and administrative purposes. The Illustration on the opposite page shows the Suruliyar Minor Basin, which lies in the Upper Vaigai river basin in the Madura district. In this case the basin contains an area of 512 square miles draining into the Vaigai. The Suruli Naddi and its tributaries have their source to the east of the watershed of the general range of the Western Ghâts, and the discharge of the streams is fairly constant, as they draw their supply from mountains 6,000 feet above the sea, which are overgrown with impenetrable forests. The average annual recorded rainfall is 26 inches only in the centre of the minor basin, but in the neighbouring hills it is taken to be as much as 95 inches in the year. There are no less than 127 separate systems of irrigation within this minor basin, having a total irrigated area of only 17,996 acres. The system of irrigation is partly from channels which are led off from the streams by means of *anicuts* or weirs across the river, but largely from tanks which receive their supply either from the catchment area above them, or in some cases from channels supplied by the rivers. Thus tanks Nos. 24 and 25, in the south-east of the map, are small rain-fed tanks, but No. 27, to the north of them, is fed by the Viranvan channel which takes off above an *anicut* or weir across the river. Tank No. 29 is entirely rain-fed. In system No. 31 the irrigation is mainly effected from the channel, which is nearly 4 miles in length, but tanks 32, 33, 34, and 35, which are fed by the same channel, store water for use when the supply in the river is deficient. There are 966 acres of irrigation under this little system. The channel runs across the drainage of the country and diverts the rainfall of $11\frac{1}{2}$ square miles into four tanks which are supplied with masonry sluices. These four tanks have a joint capacity of 25 millions of cubic feet, but, as they are filled and exhausted several times during the season, the effective annual storage amounts to nearly three times that quantity.

[1] "General Descriptive Memoirs of Irrigation Works in the Upper Vaigai River Basin," Madras, 1887.



RUSHIKULYA RESERVOIR SYSTEM.

The Lake of the Periyar Reservoir, from below the Dam.

The Fuleli Canal at Hyderabad in Sind.

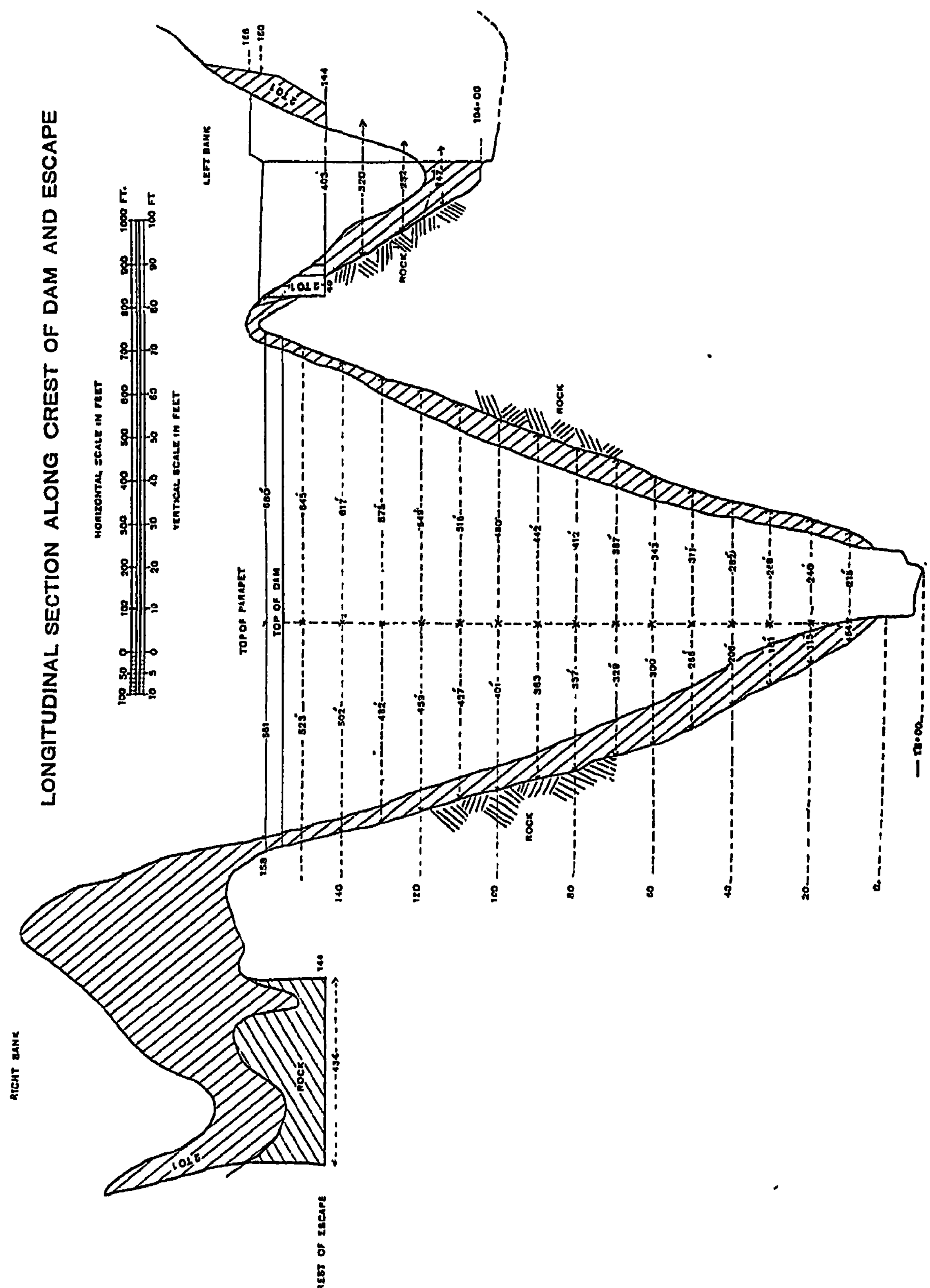
In all these small tanks it is assumed that each 200,000 cubic feet of available annual storage is sufficient for each acre of irrigation. In calculating the maximum discharges from the catchment areas above the various weirs and tanks, the formula used was that referred to on page 52, C being taken as 500 or 600 and *c* as 100.

The Rushikulya Reservoir System utilises the water of the two small rivers, Rushikulya and Mahanadi, both by direct draught on the rivers, and by storing the water in two reservoirs constructed in the bed of the streams. The Baracona Reservoir on the Mahanadi is mainly supplied by a channel from the Gulleri river which has a catchment of 170 square miles. The waterspread of the reservoir is about 4¼ square miles, the maximum depth 60 feet: the capacity of the reservoir is 2,457 millions of cubic feet, of which 2,295 millions are available for irrigation. The reservoir is formed by an earthen dam, from 10 to 18 feet crest, with inside slopes of 2 to 1, and outside of 3 to 1, with a puddle wall in the centre and the inner slope revetted with rubble. The Soorada Reservoir on the Rushikulya is formed by a similar dam of earth, 45 feet high: it has a waterspread of 7·14 square miles, and a capacity of 2,160 millions of cubic feet; the catchment is 250 square miles. It commands an area of 120,000 acres in the tract of country lying between Aska and the Bay of Bengal, and 85,000 acres have been irrigated: it is estimated that the minimum supply in the rivers can be sufficiently supplemented, from the water stored in the two reservoirs, to ensure a discharge of 1 cubic foot per second for every 100 acres irrigable during the irrigation season. The water from the reservoirs is drawn off into the channels of the rivers below the dams, and, after flowing some distance, is intercepted by the weirs at Goomsoor and Jada and diverted into the canals, from which the irrigation is effected by a series of distributaries. The capital cost of the system has been Rs. 5,000,000 nearly.

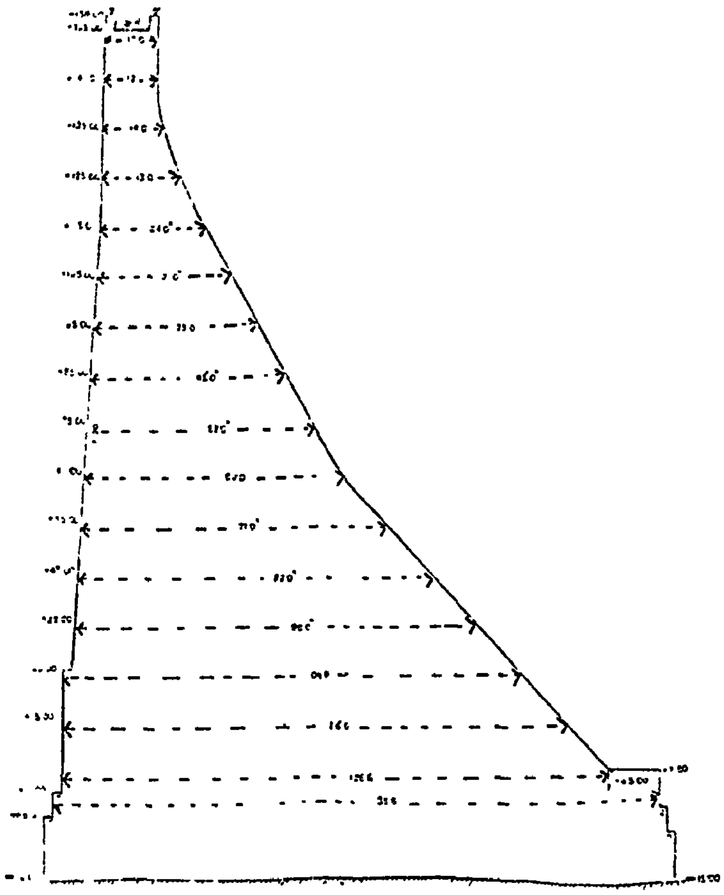
The most interesting reservoir scheme in India is the Periyar system in Madras. This striking work was designed to irrigate the district of Madura, in Southern India, where the rainfall is scanty and very uncertain, and where famines have frequently occurred. This district used to be watered by the Vaigai river which draws its supply from a catchment area, lying on the eastern side of the Ghâts which separate the British territory of Madura from the independent native State of Travancore. The supply in the Vaigai river had been used for irrigation from time immemorial, and the river is crossed by three small weirs or *anicuts* and several "coromboos" formed right across the valley, which diverted the available supply into small tanks: it has indeed been asserted that in an average year not a drop of the Vaigai water reached the sea, but the supply was most scanty and uncertain. On the western side of the Ghâts, however, the rainfall is copious and secure; it averages about three times that of the Madura district, and the discharge from the vast tracts of uninhabitated jungle, which lie in the Travancore State, passed unutilised to the sea near Cochin, down the channel of the Periyar river, which, at one portion of its course, is within a few miles of one of the tributaries of the Vaigai. The project for diverting the surplus waters of the Travancore jungles across the hills which intervene between the Periyar and the Vaigai had been put forward in various shapes since the beginning of the last century, and was finally executed from the designs of Colonel J. Pennycuick, R.E.[1] See plan on the next page.

The main feature of it is a reservoir on the Periyar river, containing 13,300 millions of cubic feet of water, of which 6,815 millions are available for irrigation between the level of the sill of the outlet and that of full supply. This reservoir is formed by a concrete dam 1,241 feet in length, and 155 feet in height from the bed of the river to the crest, above which there is a parapet 3 feet high. The dam stands in a very narrow gorge where the Periyar river passes between two hills. The section of the gorge is shown in the sketch on page 75.

[1] From whose report most of this description is taken.



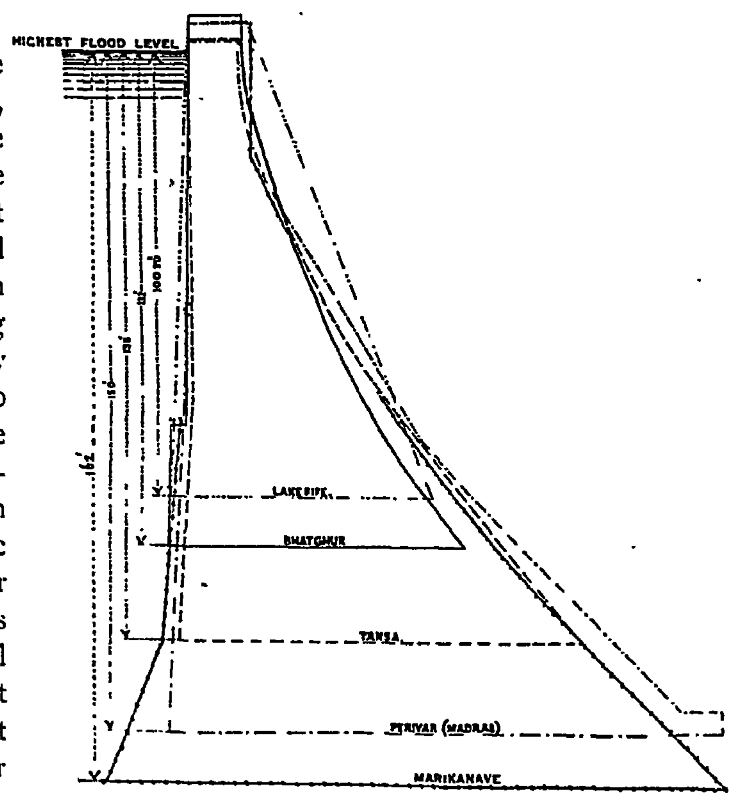
LONGITUDINAL SECTION OF PERIYAR DAM AND ESCAPES.



CROSS SECTION OF THE PERIYAR DAM.

The dam is built to the section given here. The water impounded in the reservoir is drawn off into a tributary of the Vaigai river by a tunnel cut in the rock through the intervening hills 5,704 feet in length, having an area of 90 square feet and a slope of 1 in 75. The head of this tunnel is fitted with one of Stoney's patent draw gates. From the mouth of this tunnel the water from the Periyar Reservoir flows down the river channel, for a distance of 86 miles, until it reaches a point in the plains of Madura where it is distributed for irrigation by means of a weir across the river and an ordinary system of canals. There are various regulating works in the channel of the stream between the tunnel and the point of distribution. The area which the system will irrigate is nearly 200,000 acres. It came into operation in 1896.

The catchment area above the dam on the Periyar is about 300 square miles in extent, and the rainfall on it, which is well distributed, is stated to be more than 120 inches in the year. The reservoir has a waterspread of about 12 square miles, and it is calculated that the total amount of water which can be drawn from the reservoir during the year, with the help of the supply in the Periyar river, is about 30,000 millions, which will allow rather more than 160,000 cubic feet for each irrigable acre. The loss by evaporation was assumed at 3,230 millions of cubic feet, and 500 millions are allowed for filling up the dry beds of the rivers after the hot season. The total capital outlay on this system has been about Rs. 9,000,000; the net revenue is about Rs. 290,000, giving a return of 3¼ per cent. on the outlay.



CROSS SECTIONS OF INDIAN MASONRY DAMS.

The construction of this great work was carried on under most disadvantageous circumstances: the site of the Periyar dam is in the heart of a most intensely unhealthy district, where work is only possible during a portion of the year.

Cross sections of the five most important masonry dams in India, drawn to the same scale, are shown in the sketch on the opposite page.

There is a project[1] under discussion in Bombay for the construction of a masonry dam at the head of the Pravara Valley in the Ahmednagar district. The dam will store 8,670 millions of gallons of water at a cost of about Rs. 350 per million gallons. The maximum height of the dam is designed to be no less than 250 feet above the river bed, and it will be founded on trap rock which is exposed on the surface of the river bed, and at many places in the side of the gorge. The dam will be 1,425 feet long at full supply level, and 900 feet at 50 feet below full supply. The watershed is 47 square miles, and the rainfall varies in different parts of the catchment from 150 to 450 inches in the year! The waste weir is to be 850 feet long fitted with automatic gates 10 feet by 8 feet with a waste channel through a ridge at the side of the dam.

The Marikanave Reservoir in Mysore, which is now approaching completion, will be by far the largest in India, and, as regards its gross capacity, the largest in the world. The scheme was originally mooted[2] in 1801, and has been from time to time brought forward, estimated, re-estimated, and put aside. The Madras Government raised objections to the construction of the reservoir on the ground that any interference with the flow of the Vedavati river, which supplies it, would prejudice the cultivation in the Bellary district. These objections were overcome in 1894 and the scheme was again revived and investigated, but only to be condemned once more, on the ground that the rock was not sufficiently sound at the site of the dam. In 1898 an influential committee, appointed by the Dewan of Mysore, went fully into this question, with the result that that objection was overruled and the scheme was finally approved. Preliminary operations were commenced in August of that year for the construction of the dam.

The Vedavati river, which supplies the Marikanave Reservoir, has a catchment area of 2,075 square miles above the gorge in which the dam is being constructed. The dam will be 1,185 feet long at top, and 142 feet above the river bed. As the lowest point of the foundations is 25 feet below the bed, the greatest height of the dam is 167 feet. The reservoir will store 130 feet depth of water, with a waterspread of 34 square miles, and a capacity at that level of 32,348 millions of cubic feet. The width of the dam at bottom is 150 feet, and at top 15 feet. The average rainfall on the catchment, calculated from the registers of ten towns, is 23·46 inches only. There are no less than 970 tanks in the catchment, some of considerable magnitude: the total capacity of them has been estimated at 6,500 millions of cubic feet. The whole of the land, which will be benefited by the project, is most barren and sparsely populated. During the great famine of 1876—77 one-third of the population of one portion of this tract was lost.

The discharge of the Vedavati varies greatly year by year. In 1864 it was as little as 6,588 millions of cubic feet; in 1865 it was 23,652 millions. It is thought that in very exceptional years it may be as much as 32,000 millions of cubic feet. But the project has been based on the hypothesis that the volume impounded in the reservoir in a bad year will be only 3,000 millions, in an average year 10,000 millions, and in a very good year 19,000 millions of cubic feet. These volumes correspond to a flow-off of—

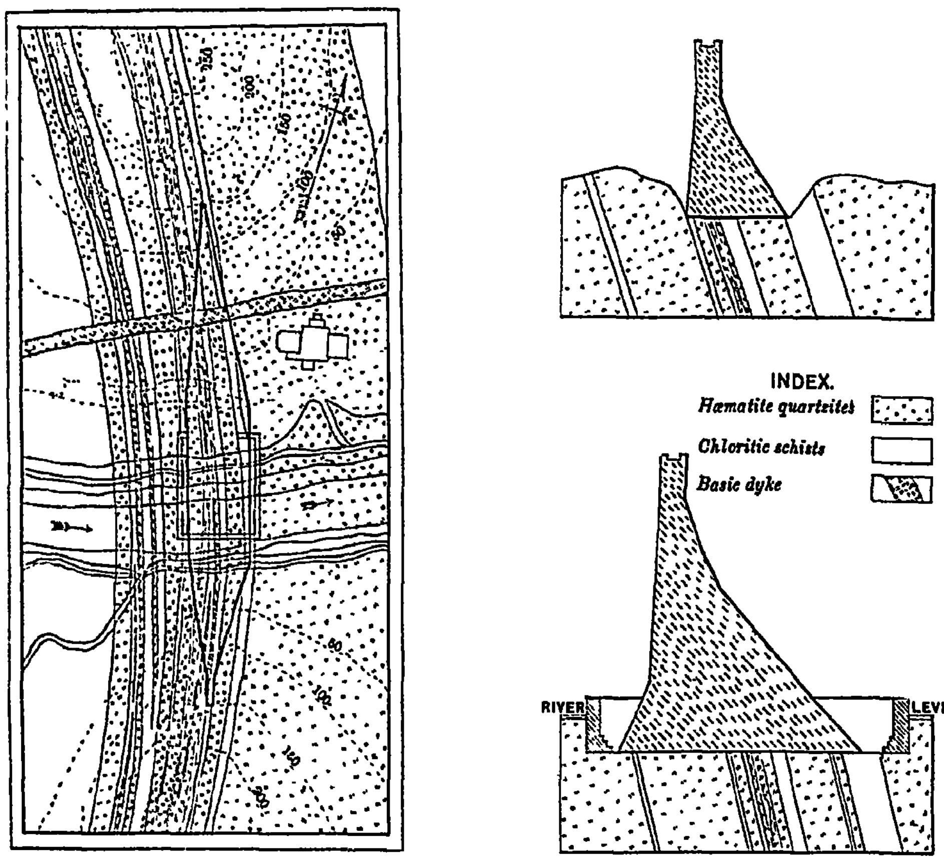
$\frac{1}{8}$th of the total fall in a bad year of			15	inches of rainfall.	
$\frac{1}{7}$th	,,	,, an average year of	24	,,	,,
$\frac{1}{6}$th	,,	,, a good year of	30	,,	,,

[1] Note by Mr. H. O. B. Shoubridge, Ex. Engineer, Bombay.

[2] "Brief History of the Marikanave Project," by Col. D. McNeil Campbell, R.E.

The total capacity of the reservoir, between the sluice level and full supply level, is about 28,000 millions of cubic feet, and its capacity at the maximum assumed flood level (142·00) is about 40,000 millions. The great Assuan reservoir on the Nile has an available capacity of 38,000 million cubic feet, and will fill every year. The Periyar Reservoir has an available capacity of 6,815 millions, and the Bhatgarh Reservoir of 4,638 millions.

The storage capacity of the Marikanave Reservoir is, it will be noticed, very greatly in excess of the normal supply to it. The reason why the capacity was made so large is interesting. It was originally[1] proposed to provide a capacity of 20,000 millions of cubic feet, which would about equal the in-flow due to the annual rainfall. But there were possibilities of cyclonic rainfalls which would not only fill a tank of this capacity, but would also require an overflow

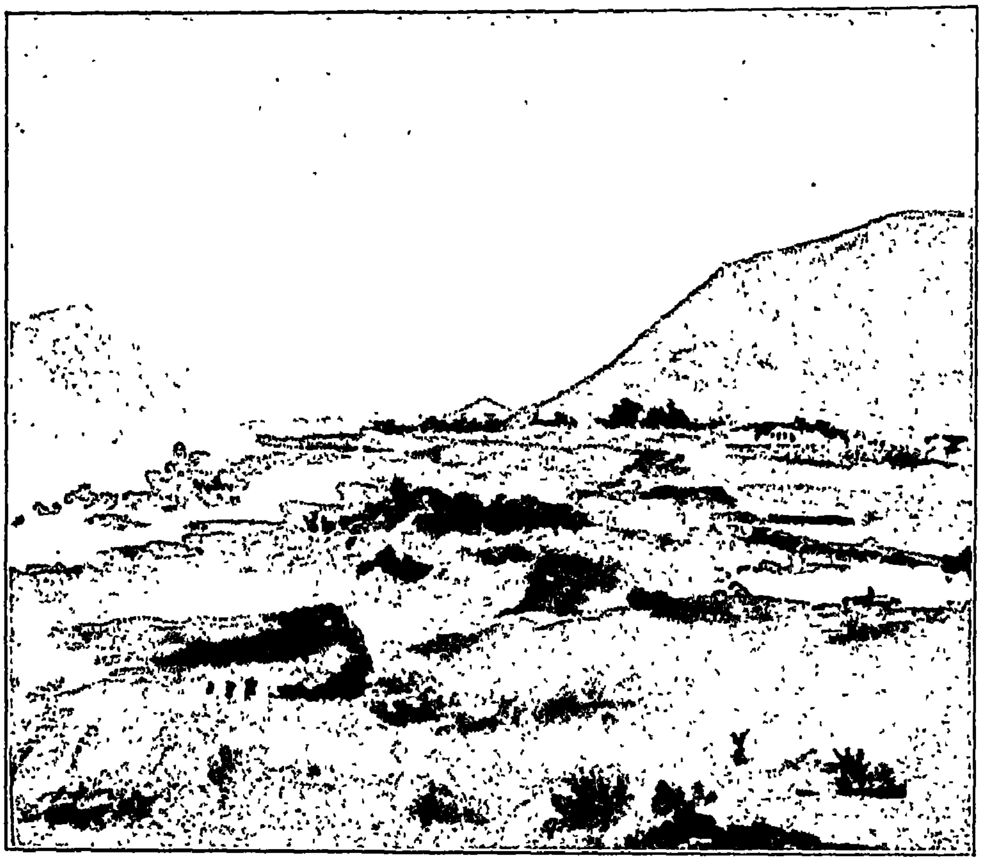


MARIKANAVE DAM. PLAN AND SECTIONS SHOWING FOUNDATIONS.

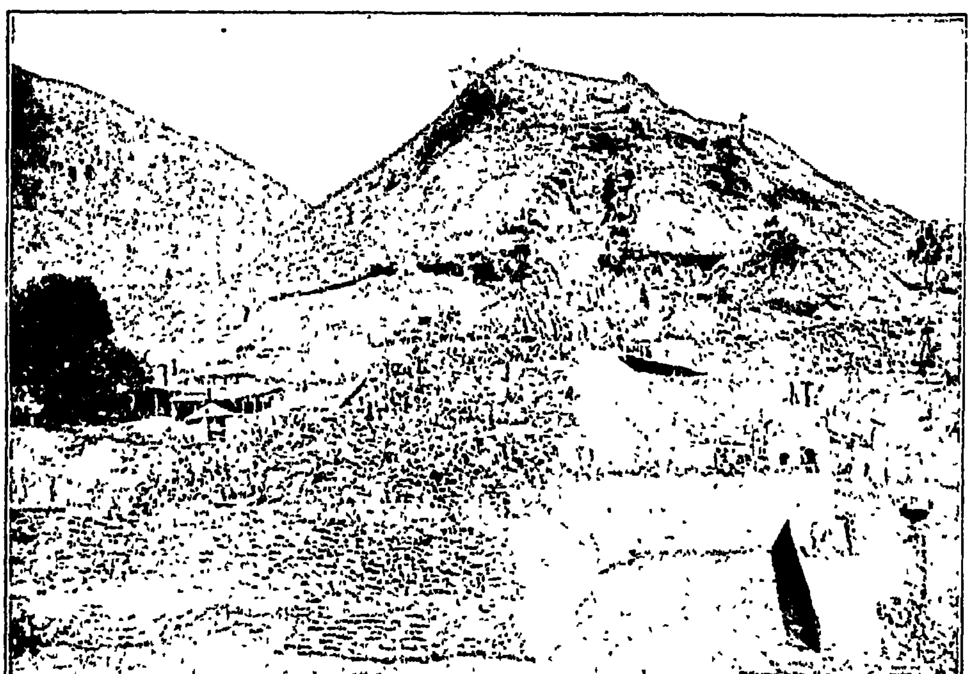
capacity of 60,000 cubic feet per second. A waste weir, to provide for such a discharge, could only be obtained by cutting a deep channel through hard rock. It was found to be actually cheaper to raise the height of the dam, and so provide for impounding the cyclonic storms, than to construct a waste weir to allow of their discharge.

As the capacity of the Marikanave Reservoir exceeds so largely the ordinary estimated supply, the full supply level will only be occasionally attained in it. It has, however, been assumed in designing the waste weir, that a maximum flood may occur when it is full to the level of the waste weir crest (130·00). The maximum flood actually recorded has been 35,377 cubic feet per second, but it has been assumed that 60,000 cubic feet may possibly pass off the catchment. This larger volume has been taken partly because it is possible that a chain of the tanks lying in the catchment may break at the time of abnormal rainfall; partly because some

[1] Note by Sir Thomas Higham, K.C.I.E., St. Louis Exhibition, 1904.



SITE OF MARIKANAVE DAM BEFORE COMMENCEMENT OF WORK.



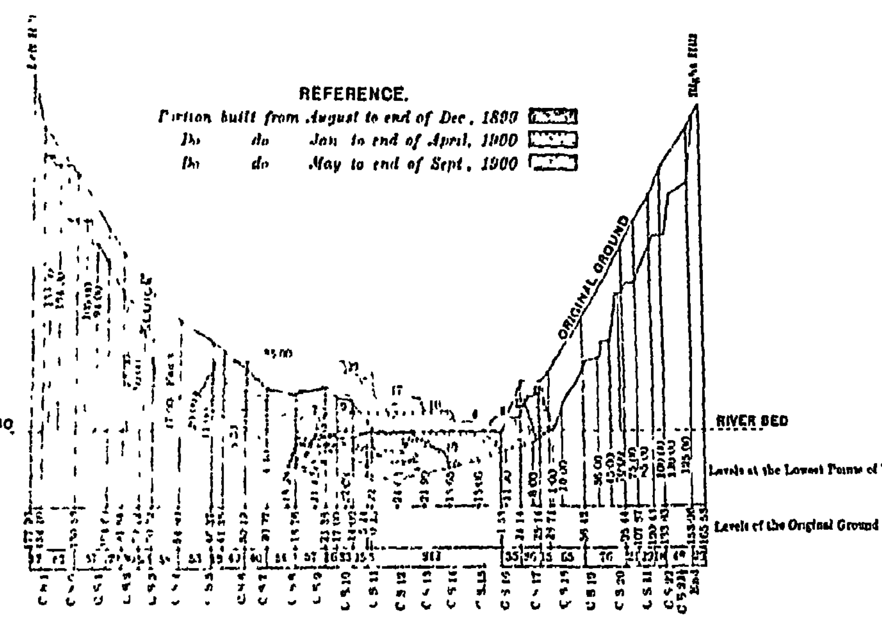
MARIKANAVE DAM UNDER CONSTRUCTION IN 1900.

[To face page 78.

doubt is felt as to whether the maximum hitherto recorded is really a maximum and whether the gauging of it was correct; and partly because the formula generally used in Madras (see page 51) gives, with C taken as 400, a discharge of 60,000 cubic feet per second. But although 60,000 cubic feet a second may pass into the reservoir, that volume will not, it is supposed, ever pass over the waste weir, as it will be impounded to a large extent in the vast waterspread of the lake. The waste weir is only 418 feet long and carries about 23,000 cubic feet a second when a depth of $6\frac{1}{2}$ feet is passing over it, or about 40,000 cubic feet in the extreme case when 10 feet is passing over the weir.

The sluice, for drawing the water off the reservoir, is designed to carry 1,047 cubic feet per second, with a head of 10 feet when the water in the reservoir is low, and with a head of 80 feet as a maximum. It is believed to be the largest sluice which has been built carrying such a discharge at so great a head. It is to be fitted with Stoney's roller gates.

The sketch on the opposite page shows the geological formation on which the dam is founded. The beds are an alternating succession of hæmatite quartzite and crystalline schists; the strike of the beds is about N.N.W., and the dip about 70 E.N.E. Some doubts were felt whether the rock was sufficiently good to stand the pressure of the dam, and to resist the percolation of water below it. It was decided that the hæmatite quartzite, on which the greater part of the dam is founded, was good, and not liable to decomposition when sealed beneath the dam; and that the comparatively thin layers of schists, though more liable to change, were no source of danger. Many specimens of the soft rock were tested and found to bear a pressure equal to 140 to 180 tons on the square foot. As regards percolation, it was thought that this would be considerable at first, but that it would tend to rapidly diminish as the fine interstices would become choked with the sediment which the water would introduce. There was no appreciable leakage under the dam during its construction up to R.L. 110·00.



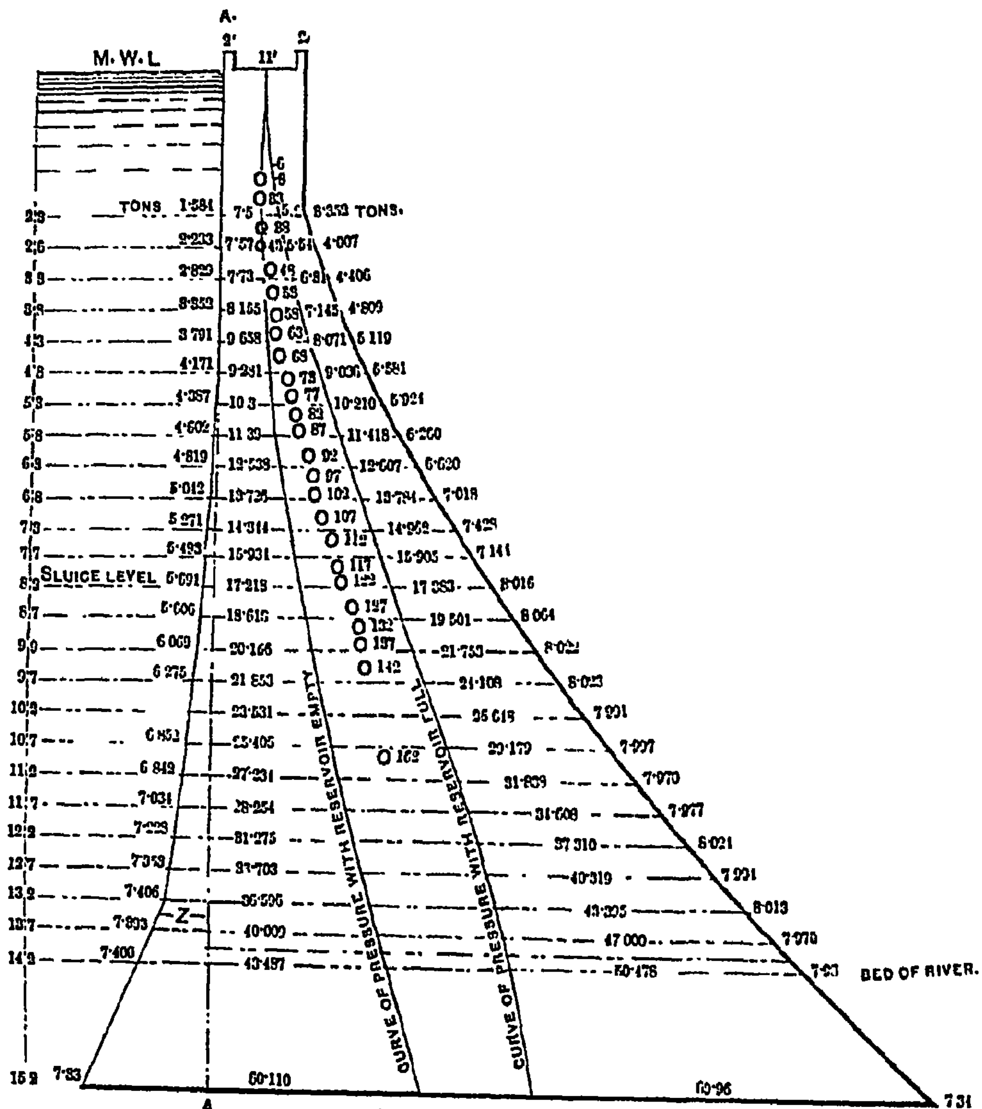
Longitudinal Section of Site of Marikanave Dam.

The gorge in which the dam is constructed is only about 1,200 feet broad at the level of the crest of the dam. The sketch on this page shows the cross section of the valley and the progress of the first three years in the construction of the dam. The discharge of the river was passed over the incomplete dam during its construction, a cushion dam being built below it 21 feet above the river bed.

The cross section of the dam is given on the next page. The conditions laid down were that—(1) the depth of water in front of the dam might be as much as 142 feet above the river bed; (2) that the specific gravity of the masonry was 2·4; (3) that the pressure per square foot was not to exceed 8 tons; (4) that the line of resistance should pass through the centre third of the dam; (5) that water should be assumed to be always up to the sluice level (60·00); and (6) that the

water in the rear would be always at bed level. On these assumptions the pressures on either toe were worked out as shown in the diagram. The dam is constructed of hæmatite quartzite rubble stone, from 1 to 10 cubic feet in size, set in mortar made from *kunkar* lime and *surki* (burnt brick).

The actual volume impounded in the reservoir will, as has been stated above, vary very greatly. But the area which the reservoir will irrigate has been calculated on the assumption

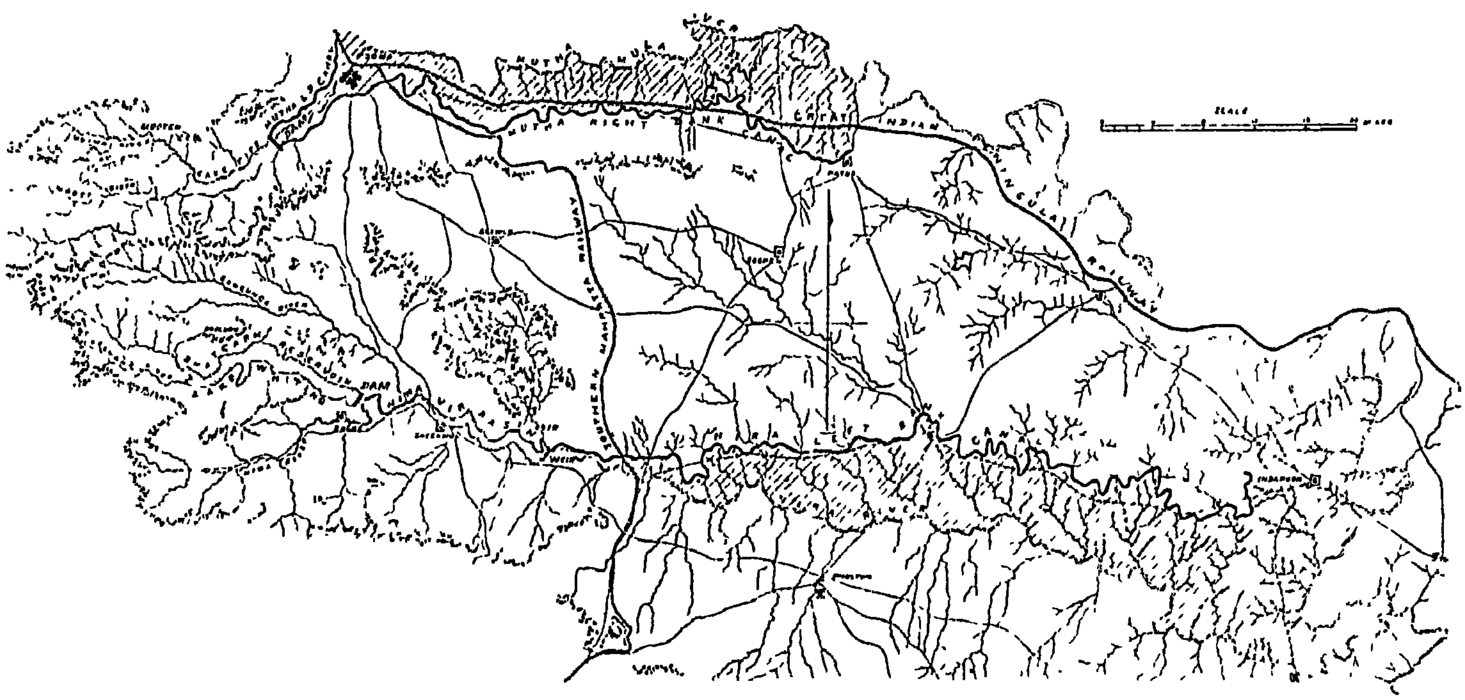


Scale 30 Ft. to an Inch.

PROFILE OF MARIKANAVE DAM. SPECIFIC GRAVITY, 2·4

that only 8,000 millions of cubic feet will be available every year. This is about 30,000 Mysore "units" of 2,61,360 feet, which is the volume taken in Mysore as that required to be impounded for each acre of rice crop. So the irrigable area is taken, at present, as only 30,000 acres. But it is hoped that in the case of so large a tank, with distributary channels properly aligned and carefully graded, a higher duty will be obtained from the water, and that ultimately it may be possible to irrigate 45,000 acres from it every year. The estimated cost of the scheme is nearly forty lakhs of rupees—about £270,000.

The reservoirs and tanks in the Bombay Presidency are in all cases constructed in hilly ground. They vary in area from 10 square miles of waterspread down to 50 acres, and in capacity from 7,000 millions to 15 millions of cubic feet. The majority of the reservoirs are constructed with earthen embankments, which vary in maximum height from 95 feet down to 29 feet, but there are six which are formed by masonry, or concrete, dams which vary in height from 120 feet to 60 feet. The most important are Lake Fife and Lake Whiting (the Bhatgarh Reservoir) near Poona, which will now be described. The Mutha and Nira rivers[1] in the Poona district of Bombay are fed from the Ghâts, where there is an unfailing rainfall of some 200 inches, and they can always be depended upon to provide an abundant supply of water during the monsoon months, although in the valleys in the eastern portion of the district in which the rivers run, the rainfall is very uncertain, and subject to frequent failure. The necessity of reservoirs in the valleys of these rivers, to store the monsoon supplies, as a protection against



LAKE FIFE AND LAKE WHITING.—NIRA AND MUTHA CANALS

famine, was recognised before Colonel Fife first brought forward, in 1863, the project for the Mutha Reservoir (Lake Fife) and the Mutha Canal which he afterwards carried to completion. This reservoir is formed by a masonry dam of uncoursed rubble nearly 3,700 feet long and 98 feet high, in the loftiest part, above the river bed: the waterspread of the reservoir is about 6 square miles, and it contains nearly 5,000 millions of cubic feet of water, of which rather more than 3,000 millions are available for irrigation.

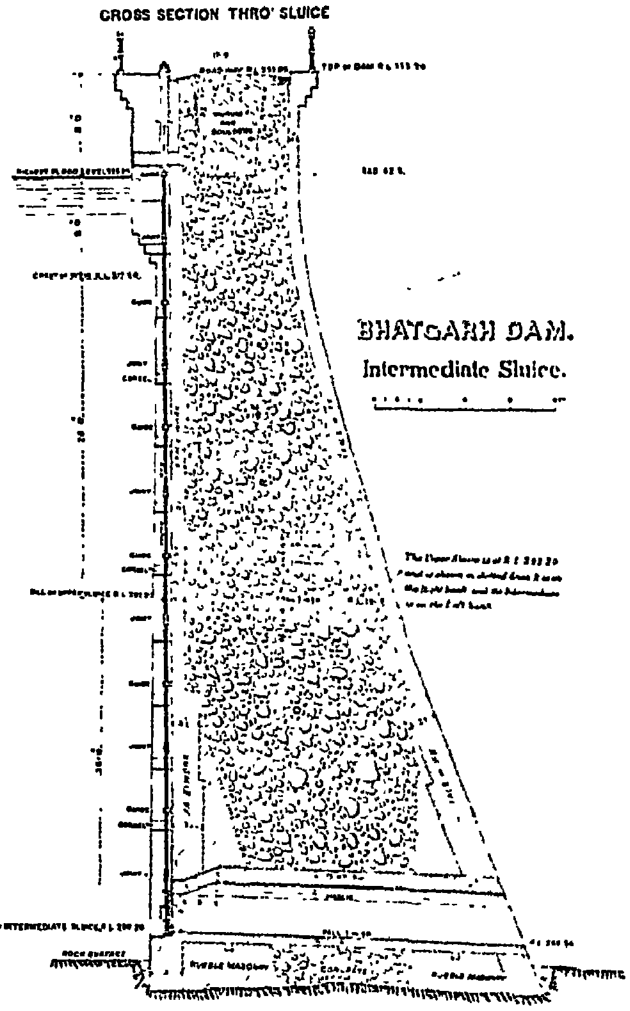
The main features of the Nira Canal System are:—

I. The Bhatgarh Reservoir, or Lake Whiting as it is now called, on the Yelwandi river.
II. The Vir Basin formed by the weir on the Nira river at Vir.
III. The main canal on the left bank of the Nira river.

The Nira river, during the monsoon months of June to October, discharges much more water than is needed for the full supply of the canal, but, after October, the supply rapidly

[2] This description of the Nira Canal and Bhatgarh Dam is taken largely from the "Report on the Nira Canal Project published by the Government of Bombay in 1892.

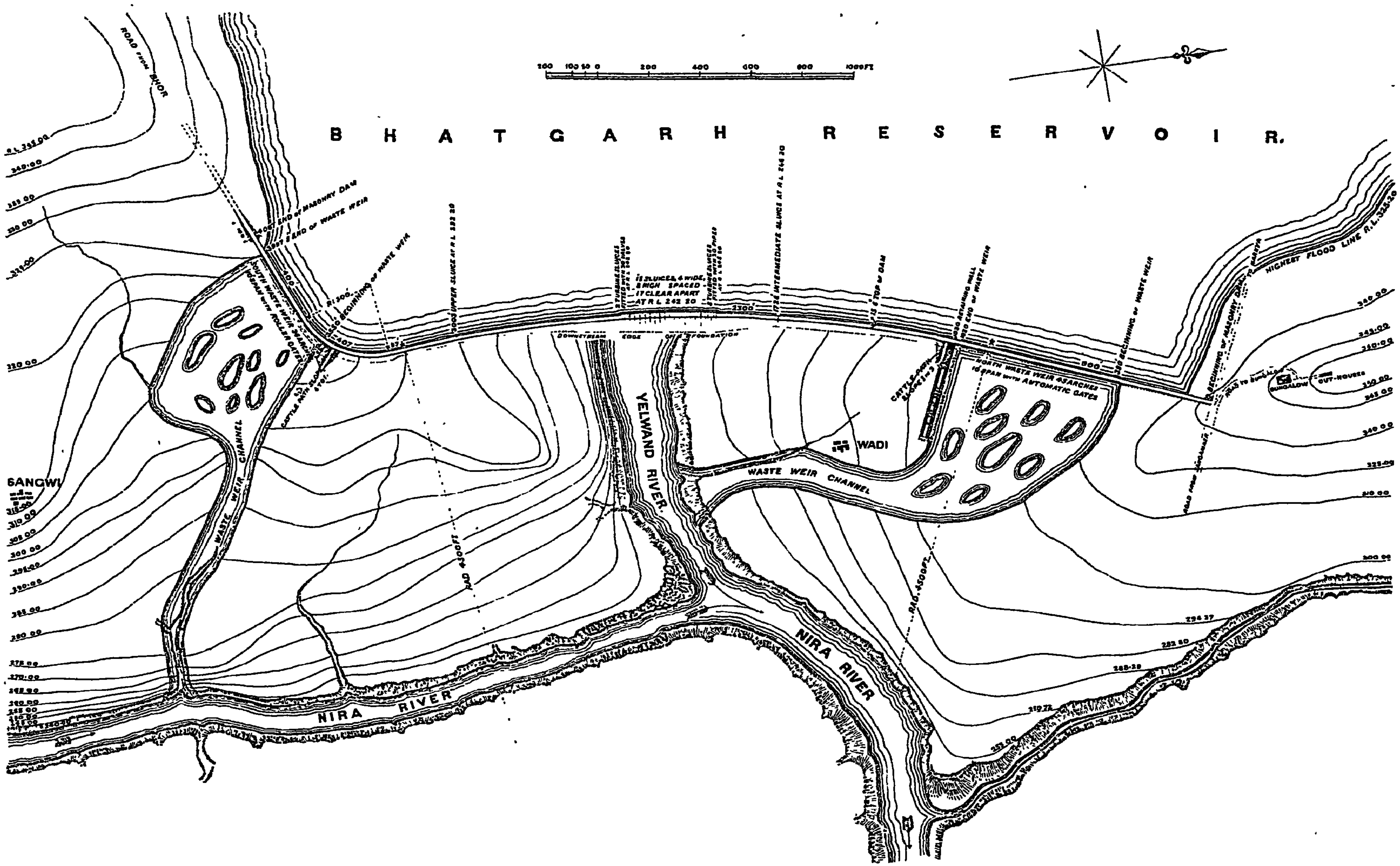
decreases, and from January to June there is practically none at all. In order, therefore, to secure an unfailing supply throughout the year the Bhatgarh Reservoir has been constructed: it contains a gross volume of 5,313 millions of cubic feet of water when full, of which 3,953 millions of cubic feet are available for irrigation. The waste weir consists of 103 openings, each of 10 feet: automatic gates are fitted to 88 of these, and the rest either with gates worked by hand or by stop planks. The water from the reservoir is drawn off into the rocky bed of the Nira and flows down it to the basin, in the bed of that river, which is formed by the head-works of the canal. These are constructed across the river at Vir for the purpose of diverting the supply into the canal. The Vir Basin impounds a certain quantity of water which is also drawn upon for irrigation. The canal, which follows a contour on the left bank of the Nira river, commands an irrigable area, between itself and the river, of about 275,000 acres, of which 75,000 acres can be irrigated under present conditions. The canal is 100 miles in length and is provided with 139 miles of distributary channels.



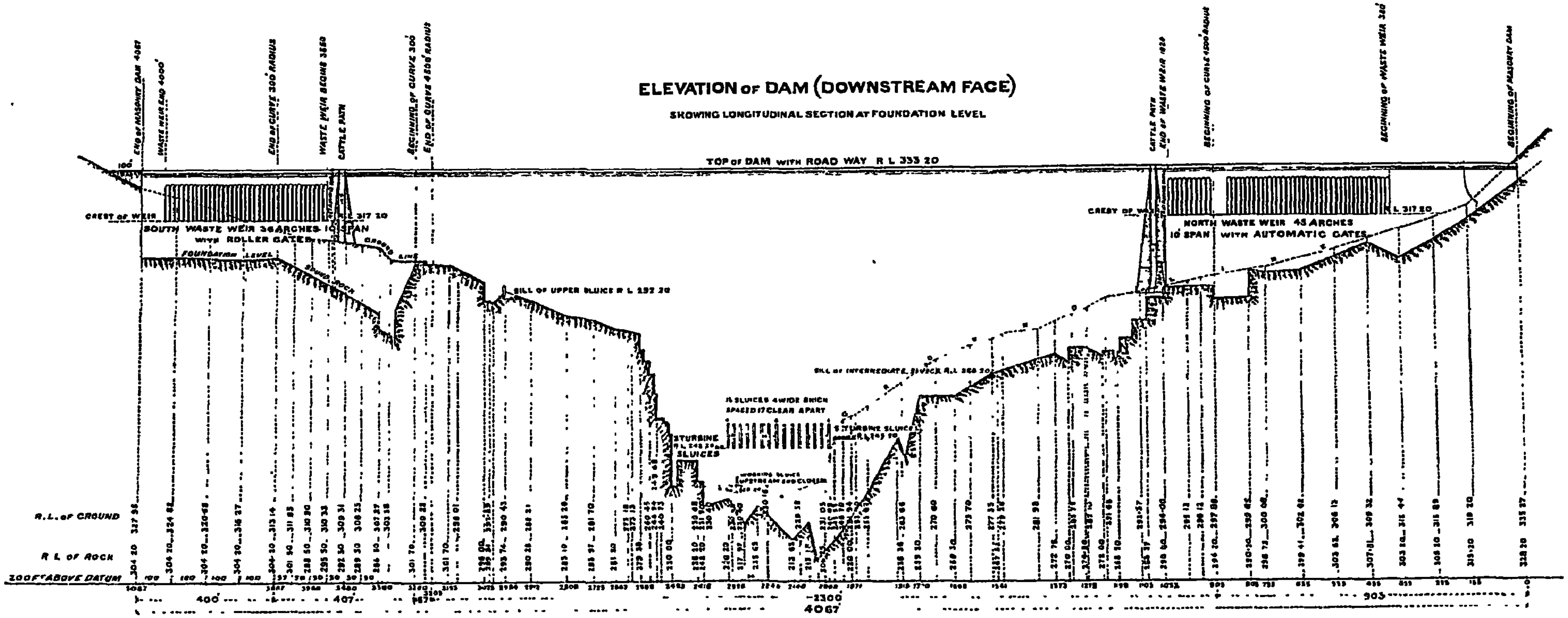
Section of Bhatgarh Dam.

The catchment area of the Bhatgarh Reservoir is 128 square miles, with an annual rainfall varying from 250 inches in the Ghâts to 40 inches at the dam site. The maximum run-off originally assumed in the case of Lake Fife (which has a catchment similar to that at Bhatgarh, but 62 square miles larger in area) was half an inch an hour, and only on one occasion since the lake was completed has the flood been known to approximate to that figure. For the smaller area at Bhatgarh the maximum run-off was assumed to be five-eighths of an inch per hour, which is equivalent to 51,600 cubic feet per second from the catchment of 128 square miles: the waste weirs have been designed to permit of the escape of rather more than this quantity from the reservoir. The reservoir failed once, in the year 1899, to fill. There was an unusually early cessation of the rains, so that although the escape sluices, which are kept open during the early floods, were closed before the usual date, there was not sufficient time to fill the lake.

The masonry dam which forms the reservoir is built on the Yelwandi just above the point where it joins the Nira river. This site was selected because the foundation was suitable for a large dam and the catchment was ample to provide the supply required, and was, at the same time, not so large as to demand excessive escapes: the site also offered advantages for the construction of suitable waste weirs and for the supply of materials for the dam.



GENERAL PLAN, BHATGARH DAM.



LONGITUDINAL SECTION OF BHATGARH DAM.

The dam, which is built of masonry and concrete, is 3,020 feet long with a maximum height of 127 feet above the lowest foundation and 103 above the bed of the river: the width at full supply level is $12\frac{1}{2}$ feet, and the maximum width of base is 76 feet. There are two waste weirs, one at each end of the dam. A roadway, 11 feet in the clear, runs along the top of it, and is carried over the waste weirs on piers and arches. The clear length of waterway of the two waste weirs is 810 feet, which is calculated to discharge the maximum flood (51,600 cubic feet per second) with rather less than 8 feet head on the crest.

The design of the dam was based on the conditions that the intensity of vertical pressure was not to exceed 120 lbs. per square inch in any part, that the resultant pressure was to fall within the middle third of the base in any portion of the section, and that the average weight of the material of the dam was to be taken at 160 lbs. per cubic foot. This may seem a high figure, but it was found that the actual weight of the structure was quite equal to it. Some of the stone used weighed as much as 190 lbs. to the cubic foot, and it averaged 183 lbs.; and concrete made of gravel, metal, and mortar was 154 lbs. to the cubic foot. It may be noted that the weight assumed in the calculations of the Tansa Dam of the Bombay Waterworks was 150 lbs. per cubic foot; in the case of the Quaker Bridge Dam, for the water supply of New York, the figure taken, which was determined by experiment, was 156·25 lbs. to the cubic foot; in the Vyrnwy Dam the actual weight of the materials is 160·8 lbs. per cubic foot; and in the Ternay Dam in France the assumed weight was as high as 167 lbs. per cubic foot. The figure of the cross section of the Bhatgarh Dam, was worked out, by a graphic method, to fulfil the conditions stated above: the intensity of pressure per square inch was calculated from the formula

$$p = \text{intensity of pressure} = \frac{R}{A}\left(1 + \frac{6v}{x}\right),$$

where R is the vertical component of the resultant of the weight and water pressure; A the area of the base at each section considered; x the width of the base in question; and v the distance of the line of resistance from the centre of the base. The pressure calculated by M. Bouvier's theory would be higher than those given in the Bhatgarh Dam.

The mortar used in the work is known to have a crushing strength, when one year old, of fully 700 lbs. on the square inch: the maximum pressure, which occurs at the up-stream toe when the reservoir is empty, is 117·5 lbs. per square inch, so the factor of safety is a high one. Some existing masonry dams in Europe have higher pressure than will ever be reached in the case of the Bhatgarh Dam: thus:—

Villar Dam (Spain)	150 lbs. per square inch	on	up-stream	toe
Gileppe „ (Belgium)...	150	„	..	down-stream	„
Alicante „ (Spain)	171	„	„	„	„
Bau „ (France)	155	„	..	up-stream	„

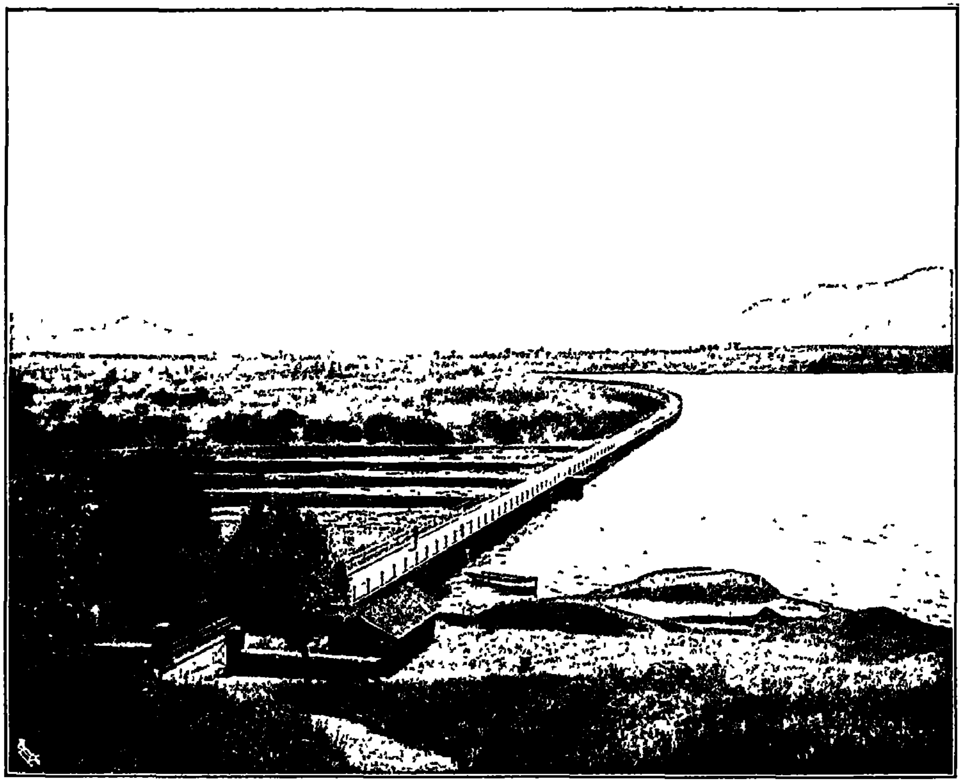
In the original design of the Bhatgarh Dam it was proposed to construct it entirely of rubble masonry. The excellent results which were obtained, however, with samples of concrete used in the weir at Vir, led to the substitution of concrete for rubble masonry in the hearting of the Bhatgarh Dam. The result of a series of experiments with blocks (10 inches by 10 inches by 15 inches) of concrete at Vir showed that the average crushing weight was 400 lbs. on the square inch: the concrete at Bhatgarh gave a corresponding result of 375 lbs. So it was determined to employ concrete, with blocks of rubble embedded in it, where the pressure did not exceed 60 lbs. on the square inch. The base of the dam, where the pressure exceeds 60 lbs. on

the square inch, is built of uncoursed rubble between faces of hammer-dressed block-in-course masonry varying from 3 feet to 15 inches in thickness. In laying the foundations, the rock, at the down-stream toe, was dressed throughout with a slope downwards towards the centre of the dam; and, similarly, at the up-stream toe, it was dressed so as to be generally at right angles to the up-stream batter of the face, which is 1 in 50. The centre portion of the foundation was blasted out, so as to present a rough base everywhere.

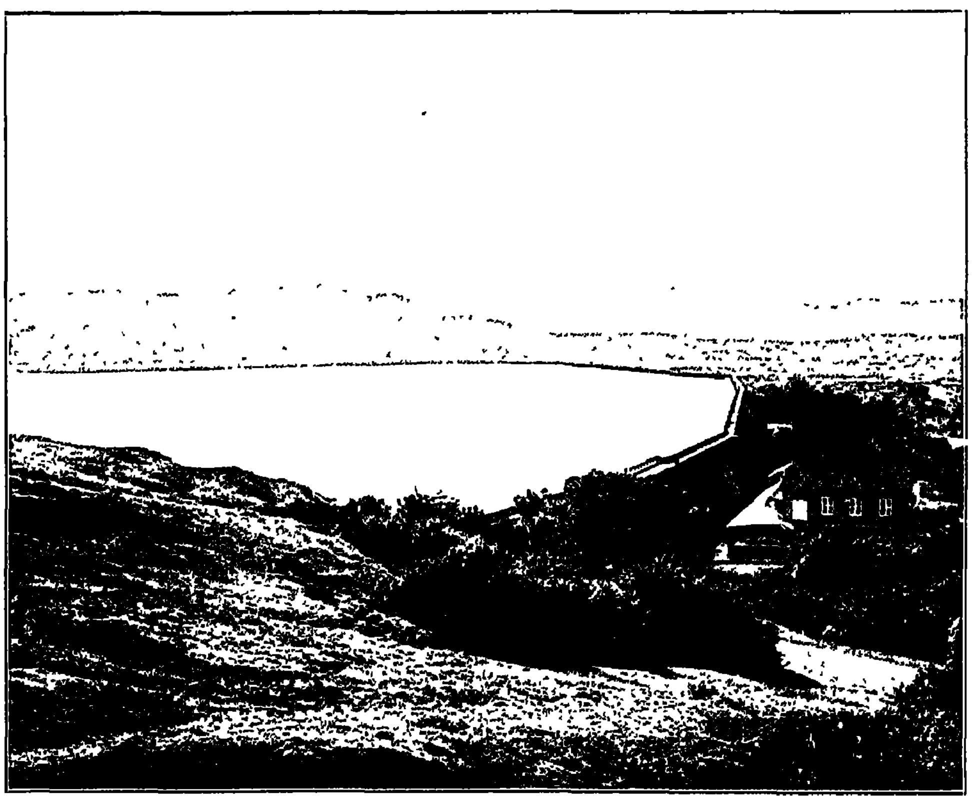
The dam is pierced in the centre by 15 under-sluices (Plate page 84) each 8 feet by 4 feet, which provide an escape for the earlier floods of the year before it is necessary to close the gates in order to fill the reservoir. The object of these under-sluices is to prevent the deposit of silt in the reservoir by allowing the floods to pass through them at a low level instead of over the waste weirs. As there is a danger of the sluices being choked by timber and brushwood, so that they could not be closed when necessary, there are screens in front of them formed of rails placed horizontally 1 foot apart. These rails are only 2½ feet from the sluice: it would have been better if they had been placed at a greater distance in front. The rails have proved to be an ample and sufficient protection against heavy timber, but brushwood accumulates on the rails, and on one occasion prevented for a time one of the gates from being quite closed. It is found that, after the first heavy flood in July, the river can be discharged through the fifteen sluices with a head varying from 4 to 15 feet, and that when it falls to 8 feet it is possible to clear away the accumulation of brushwood. The fact that it is always possible to clear the protective screens before it is necessary to finally close the gates for the season, considerably reduces the risk of failure to close the gates. The gates are now closed always on the 31st of July and sometimes earlier, so that there may be security that the lake will always be filled.

The question of the efficiency of these under-sluices in prolonging the life of the reservoir has been a matter of controversy. On the one side it was held that, as the water must head up to 8, 15, or sometimes even 30 feet above the sluices, in order to pass the early floods, the reduction in the velocity of flow in the reservoir, owing to the greatly increased section of waterway, must be so great that a large proportion of the silt held in suspension must, in any case, be deposited; and it was said that, although the sluices would certainly have some effect in the direction indicated, that effect would be comparatively small, and not worth the expense and risk which the sluices involved. On the other hand, the arguments[1] in support of the theory that the sluices would be effectual in prolonging the life of the reservoir were that in an average year the quantity of water passed through the sluices amounts to 30,000 millions of cubic feet, or nearly six times the contents of the reservoir. Experiment had proved that during the first monsoon floods the silt held in suspension was quite 1 part in 100. If there were no sluices, the reservoir would fill when the floods were most heavily laden with silt, and subsequently the water would be discharged by the waste weir after the greater proportion of silt had been deposited in the lake. It was therefore probable that silt to the extent of at least 1 in 500 would be left in the reservoir, which at this rate would be silted up to waste weir level in eighty years. The sills of the sluices are 12 feet above the bed of the river, the fall of which is 5 feet a mile. From observation it is found that in ordinary years the floods are discharged with an average head of 15 feet, and water is ponded up for a distance of 3 miles above the dam; consequently a certain proportion of the heaviest silt is still left in the reservoir, owing to the velocity of the floods being checked, but the distance from the sluices being so short, there is not sufficient time for all the silt to be deposited, and the greater portion is carried off. The estimate that two-thirds of the silt that would otherwise be deposited in the reservoir would be passed through the sluices is probably a low one. The fact also remains

[1] "Report of the Nira Canal Project," published by the Government of Bombay.



Lake Whiting on the Nira Canal, Bombay.



Lake Fife on the Mutha Canals, Bombay.

[To face page 86.

that the area of the backwater above the dam during the monsoon, when the river is discharged with an average head of 15 feet, is less than one-thirtieth of the whole area of the reservoir, and therefore, at the time when the greatest amount of silt is held in suspension, twenty-nine thirtieths of the whole area is uncovered, and consequently no silt can be deposited there. The minor danger, therefore, only remains from pebbles, gravel, and heavy particles left at the point where the check must occur. Judging from the way in which the large scouring sluice in the main weir at Vir has acted, it appears more than probable that eventually, when the basin has silted up to the sill of the sluices at Bhatgarh, a new river-bed will be formed, extending possibly for 6 or 7 miles above the dam, and an equilibrium will be established, the silt deposited in one season being brought forward and carried along the new channel till it is passed through the sluices, the result being that silting up will be confined to the area up to the 15-foot contour, and the main body of the reservoir will always be kept clear.

The sluices have now been in operation for about twelve years, and the lake shows no sign of silting as yet, except for a few hundred yards up-stream of the sluices, which is a matter of no importance. Cross sections of the lake are taken to determine the volume of silt which is deposited. In 1901 the quantity deposited above the sill of the under-sluices was only 2·9 millions of cubic feet; in 1902 it was 5·9 millions; in 1903 it was 3·77 millions. The decrease in 1903 was probably due to the under-sluices being kept open longer than in 1902.

The waste weir is divided into two portions. The northern portion has forty-five vents and the southern one thirty-six vents, each 10 feet wide, fitted with automatic gates, so that the water can be impounded up to the level of the top of the gates, which is 8 feet above the waste weir crest. A description of these automatic gates is given in Chapter XI. The two weirs are capable of discharging rather more than 56,000 cubic feet a second.

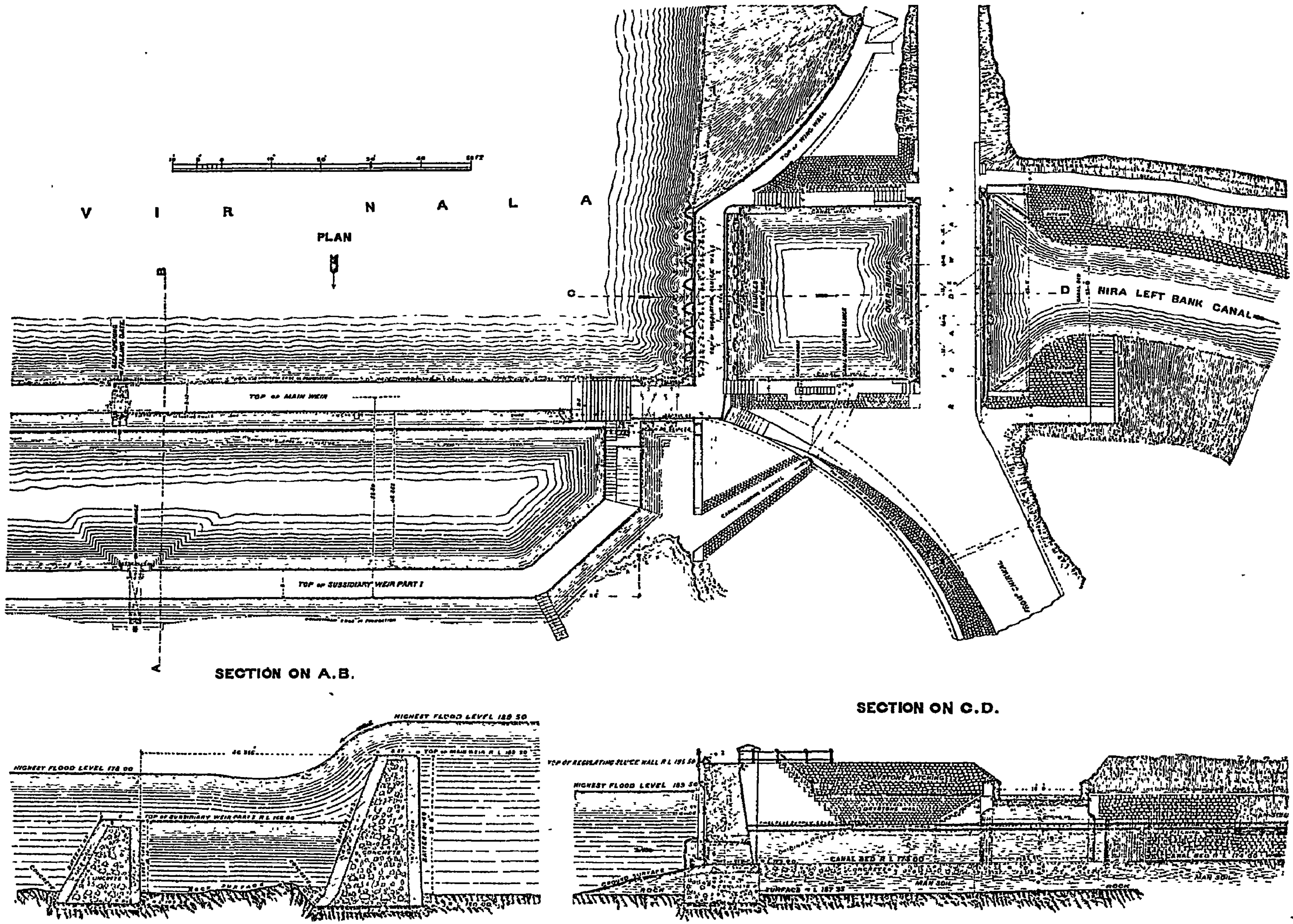
The head-works of the canal on the Nira river consist of a main weir, two subsidiary weirs, and a head-sluice or regulator for the canal. The weir, which is built on the rocky bed of the river, extends across both the Nira river and the Vir Nala, which joins the main river at this point. The main weir has a clear length of overfall of 2,273 feet, the crest being 42 feet above the original bed of the river. The breadth of the weir at the crest level is 9 feet, and at river bed 26 feet. The batter of the up-stream face is 1 in 40, and of the down-stream face 1 in 3 for a height of 29 feet from the top, and 1 in 2 below the foundations. The base of the weir, up to 26 feet from the crest, is constructed of heavy rubble masonry, the rest being of concrete laid between two faces of rubble, 2½ feet thick on the down-stream, and 2 feet on the up-stream face. The crest is curved at the up-stream edge, and covered with rubble paving 9 inches thick. (See Plate on page 88.)

There are two sluice openings in the curved portion of the weir which tend to keep a clear channel in front of it: they are closed, when the floods subside, by means of needles. There is also a scouring sluice, with a falling gate in the centre of the weir across the Vir Nala. The under-sluices—if they can be so called—in this weir are remarkably small; there are only two sluice gates, each 3 feet by 4½ feet, with sills 12 feet below the weir crest, and 3½ feet below the gates of the canal head-sluice. They are said to have proved effective, but it is admitted that they ought to have been larger.

The canal itself follows a contour more or less on the sloping ground along which it runs: it crosses heavy drainages for which no less than 117 drainage works—aqueducts, culverts, and superpassages—have been constructed. One of these is illustrated on page 248.

Some of the reservoirs in Rajputana are noteworthy. Most of the tanks[1] in Ajmere and Merwara were constructed before the Mutiny. They are generally formed by earthen embankments

[1] Note by Mr. Manners Smith, dated Dec. 7th, 1904.



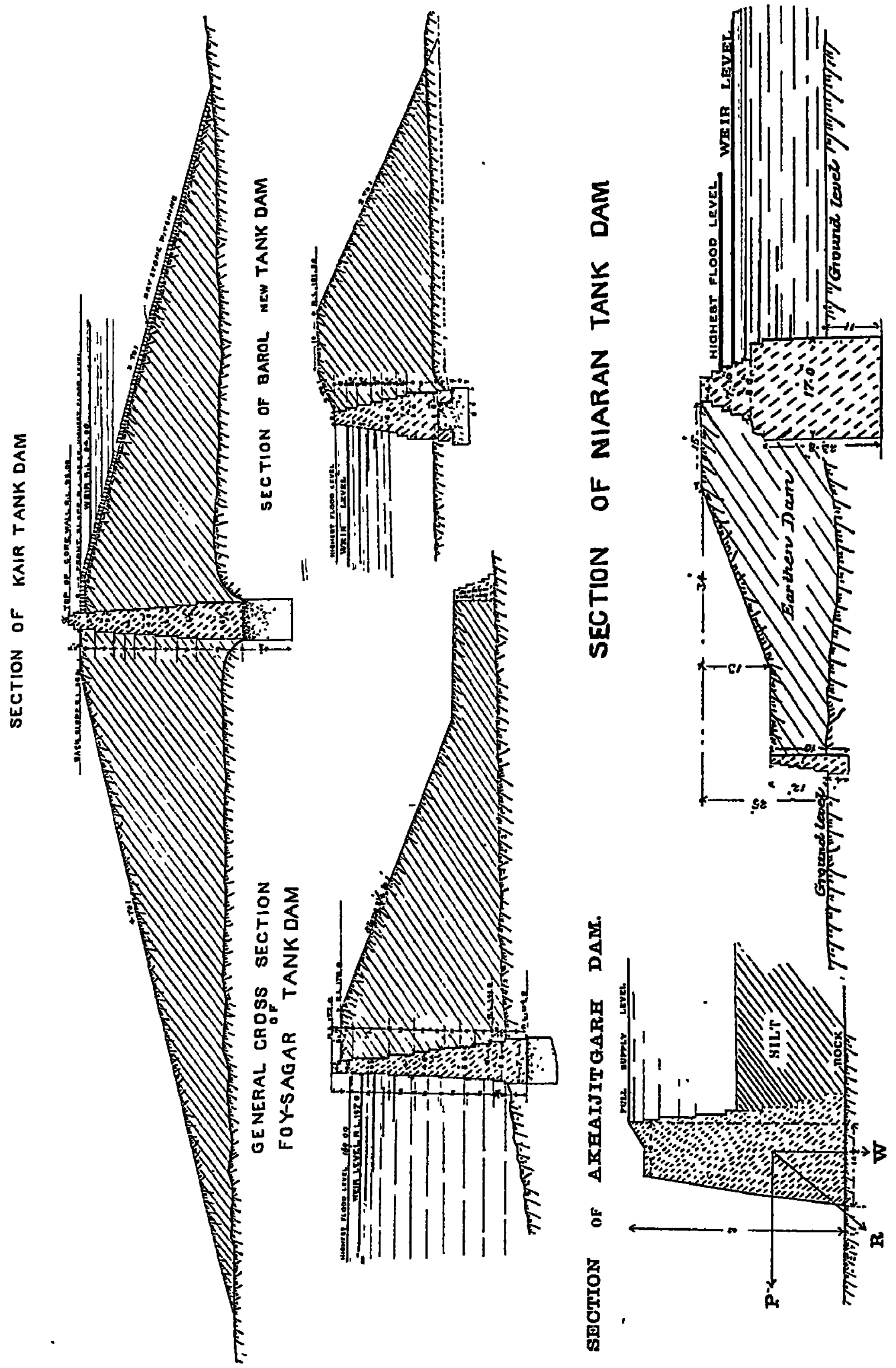
NIRA CANAL. HEAD-WORKS AT VIR WADI.

retained by a masonry face wall and backed with a masonry toe wall at the foot of the back slope, as shown in the case of the Niaran Tank Dam on page 90. But the Akhaijitgarh Tank is formed by a masonry dam founded on rock. The section of this dam, which is also given on page 90, is remarkable. In its highest point the dam is 42 feet high, and the full supply level is the crest of the dam itself. When the reservoir is full to the crest level, the resultant of the pressures at the highest point of the dam, far from being within the middle third, is actually beyond the toe of the outer slope, and there is theoretically a tension on the up-stream toe of about 40 or 50 lbs. on the square inch. The dam nevertheless has stood for half a century! Another remarkable example, shown on the same page, is the Foy Sagar Dam, which was constructed during the famine of 1890; it has a face and toe wall with an earthen embankment between them. The face wall, which is about 30 feet high, has a mean thickness of only about one-eighth of its height! When the tank is empty it acts as a retaining wall to the earthen embankment, and apparently has, hitherto, done so with success; but it is much lighter in section than seems safe, and much lighter than the other examples which are given in the same illustration. The earthen banks in Rajputana are often constructed with masonry core walls, as in the case of the Khair Reservoir, the section of which is given on page 90. These core walls are generally very thin, and one, at any rate, of their chief uses is to prevent rats or other animals making holes through the banks. It is generally considered that, if water can be stored in Rajputana at the rate of 3,000 cubic feet per rupee that the works will give a good return. In the native State of Jaipur the works return 4·92 per cent. on their capital cost, the gross revenue averages Rs. 7·93 per acre, and the working expenses are Rs. 1·83 per acre. The quantity of water allowed per acre is 100,000 cubic feet, and this is inclusive of losses from evaporation and absorption. The Ramgarh Dam[1] in Jaipur is made entirely of sand, of such an extremely friable nature that high winds blow it away. To keep the sand in position it is covered over on the embankment by a layer of broken stone 18 inches deep. The sand bank is 1,080 feet long, 90 feet high in the highest point; the top width is 30 feet and the base 570 feet. The high flood level is 70 feet, but the reservoir has, so far, never filled above 53 feet. The embankment has a core wall, of sand and clay mixed, in the centre of the bank; it is 20 feet thick at the base with a batter of 1 in 12. The core wall is carried 10 feet down into the bed of the river, but no impervious stratum was found at that, or at a greater, depth. It is contemplated that there will be percolation under the dam, and the core wall is only intended to prevent percolation through the bank itself. Any percolation under the embankment is allowed to pass freely through broken stone placed at the toe of the outer slope. It must be admitted that the work is a bold one, but it is also successful.

Earthen embankments of great height need to be founded with at least as much care as those of masonry. The surface soil should in all cases be removed, and the nature of the strata below should be carefully examined by borings to see that the soil is homogeneous, sufficiently impermeable to water, and capable of bearing the pressure which will be placed upon it. If permeable strata are found at the site of the proposed embankment, they must either be removed, cut off by curtain walls of puddle, or sealed over to prevent percolation and upward saturation of the bank. The foundation should be benched so that the new soil of the embankment rests on horizontal tables, or on tables slightly inclined towards the centre of the dam. The benches should be so cut that no step, running at right angles to the axis of the embankment, is continuous across the width of foundation. A good foundation[2] should be homogeneous and compact; it should not yield when wetted nor slip or settle under the weight of the

[1] Note by Sir S. S. Jacob, K.C.I.E., dated Dec. 6th, 1904.

[2] "Indian Storage Reservoirs with Earthen Dams," by W. L. Strange (Messrs. E. & F. N. Spon).



SECTIONS OF TANK DAMS IN RAJPUTANA

dam. Rock is, of course, best, provided that it does not slope down-stream, as this would tend to cause a slip. The "murum" of the Bombay Presidency, when compact, is good. Next to these come the hard clay soil (*mán*), the brown and red soils, and the black "cotton" soil. All these require special precautions for drainage, as they yield under a heavy weight when sodden, and are liable to slip. All soils which are light and powdery, especially those which contain carbonate of soda and deliquescent salts, are quite unsuitable. The thorough drainage of the bed of a high earthen embankment is a matter of vital necessity; it is therefore desirable to select the site of a dam where it is possible to rapidly drain off the subsoil water into natural drainage lines. The dimensions of earthen embankments of tanks and reservoirs in India follow no fixed rules, but generally inner slopes of 2½ or 3 to 1, and external slopes of 1½ or 2 to 1 are used, and many engineers favour the rule that the width of bank at the water-line should be equal to the total depth of water against the bank at the point. Mr. Strange, in his book on "Reservoirs in India," gives the following table as suitable for earthen dams in ordinarily good soils :—

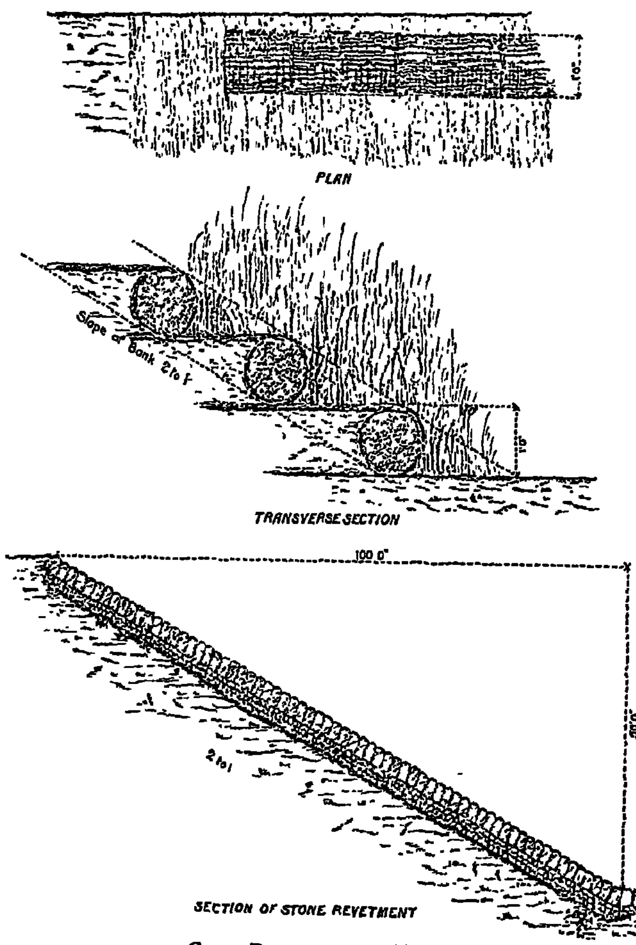
Height of Dam above Ground Level.	Height of Top of Dam above H.F.L.	Top Width.	Slopes.		Width of Dam at H.F.L.
			Up-stream.	Down-stream	
	Feet.	Feet.			Feet.
15 Feet and under ...	4 to 5	6	2 to 1	1½ to 1	20 to 23½
15 Feet to 25 feet ...	5 to 6	6	2½ to 1	2 to 1	28½ to 33
25 Feet to 50 feet ...	6	8	3 to 1	2 to 1	38
50 Feet to 75 feet ..	6 to 7	10	3 to 1	2 to 1	40 to 45

Puddle cores are not commonly employed. It is desirable to use, as far as possible, the same kind of soil throughout an embankment, so as to ensure equal settlement, and to lay the material in horizontal and shallow layers, so that it may be well consolidated as the work proceeds. Earthen embankments rarely, if ever, fail from direct hydrostatic pressure; they usually fail, either from the washing of waves cutting through a too narrow crest, or, more commonly, from saturation of the bank and consequent slips in the embankment. The first danger is prevented by raising the crest of the embankment well above the maximum water-line, and by revetting it securely with some strong material—rubble stone if possible. It is desirable to keep the crest of a high embankment at least 6 feet above the highest water level, and, when the length of the reservoir is in the direction of the highest winds, this may be advantageously increased.

The plate[1] opposite page 96 shows the form of compound dam which has been accepted in Bombay for an embankment, founded on rock, which, in its highest point, sustains a water pressure of nearly 100 feet. The heart of the embankment is of earth, but the toes of it are of dry stone. These stone toes decrease the volume of the embankment and add greatly to its stability both by their extra weight and by the facilities they afford for the drainage of the heart of the embankment. Fig. 2 shows the method adopted for intercepting the percolation which may occur between the dam and its foundation where the bed is rock, and Fig. 4 shows the corresponding measures where the foundation is on soil. In the latter case there is a series of small puddle trenches very carefully worked, on the up-stream side, parallel with the main central one, which prevent subsoil flow along a definite plane. On the down-stream side

[1] Taken by permission of Mr. Strange from his book on "Reservoirs."

there is a similar series of trenches, but these are filled with porous material to form the "foundation drains." This material is arranged with coarser particles at the bottom and the finer ones above, with a layer of sand at the top to stop the infiltration of silt into the drain. These trenches are about 300 feet long, falling uniformly to the point where they are connected with cross drains leading to the outfall. These drains are sufficiently remote from the reservoir to prevent any possibility of leakage into them from it. It is believed that this system of drainage is far superior to that of parallel drains at right angles to the outer line of the dam which is often adopted. The practice of reducing the side slopes above high flood level to 1½ to 1 which used to obtain in Bombay is now condemned, as it does not allow a margin for making up excess settlement. The crest wall illustrated in Fig. 1 is now preferred. The advantages of the crest wall are that it protects the dam to its extreme top from wash and from vermin and from vegetation; it acts as a wave breaker; it lightens the top of the dam and saves a large quantity of earthwork; it facilitates compensation for settlement of the dam and gives a better finish to the work: it is said, also, to effect some economy when the dam is high.



Grass Revetments in Tanjore

The revetment of the inner slope of an earthen embankment is a matter of great importance. Stone revetments are made from 2 feet to 4 feet in thickness, and usually cover the area of the bank lying between low-water level and the crest of the bank. In some tanks in Madras a grass or reed revetment is used as shown in the sketch on this page.

This form of revetment is described[1] as follows:—"The material is a reed which grows on the margin of rivers, or on the islands subject to inundation, and generally in any marshy locality. Like all of its species, it grows in joints, reaching a height of sometimes 10 or 12 feet, and at every joint is an eye, from which, when buried in the soil, a fresh plant will spring. The mode of construction is as follows:—The reed is first tied up into rollers or fascines about 1 foot in diameter and 10 to 20 feet long, a layer of reeds is then laid transversely to the line of bank, and on this the roller is placed, the root end of the reed being inwards; the upper end is then folded over the rollers; as soon as a sufficient number of the latter have been laid lengthwise along the top of the bank, the whole is covered over with soil, and is well rammed or trodden down, and so the first step in the bank is made. Immediately above and behind the front roller another transverse layer is placed, and on this a fresh line of

[1] "Lectures on Irrigation Works in India," by Colonel T. H. Rundall, C.S.I., R.E.

fascines is laid, over which the ends of the transverse layer are again turned and covered with earth, and so the process is repeated until the revetment has reached the required height. When completed it presents the appearance of a series of steps; it is then watered regularly once or twice a day, according to the season or the state of the weather, and after a few days, the eyes at the joints of the reeds begin to shoot, and in a short time a forest of reeds springs up and presents an impenetrable barrier to the action of any ordinary wave. This kind of revetment admits of earth and sand being retained at a steeper slope than would otherwise be possible. By this simple expedient the rivers in the Tanjore Delta are entirely regulated, there not being a stone procurable within many miles."

The saturation of an earthen embankment may occur either by water finding its way into the interior of the bank through the surface of the inner slope, or by water being forced up into it from below: the latter event is more liable to occur when the embankment stands on rock which may have fissures in it. In either case the result may be that the interior or base of the bank becomes softened and is unable to withstand the weight, both of the water and of its own mass, and the bank settles, or, may be, slides horizontally on its base and a breach occurs. To prevent the saturation of the bank from its own surface, the best plan, of course, if it be feasible, is to make that surface impermeable to water by covering it with a water-tight layer: that plan must be more efficient than inserting an impermeable diaphragm (like a puddle wall) in the centre of the embankment, because it leaves the whole embankment behind it available to resist pressure, whereas, in the case of the puddle wall, only half the embankment is efficient if the half on the water side is supposed to be saturated. It is for this reason that some engineers prefer to place puddle on the inner slope rather than in a puddle wall; but the objection to the system is that, on the surface, even when protected by rubble pitching, the puddle is liable to crack during the dry season, when the water is low, and fail to be water-tight when it rises; but a puddle wall, as it lies in the centre of the bank and is protected from the weather, is more certain to remain in a water-tight condition.

On pages 94 and 95 statistics are given of the principal tanks in Bombay, and, on page 96, of some tanks in Rajputana and Central India. The figures, which give the cost per million cubic feet stored, are based on the actual direct cost of the "works" alone, and do not cover charges for establishment, tools and plant, etc.

PRINCIPAL TANKS AND RESERVOIRS IN BOMBAY: CAPACITY, WATERSPREAD, AND FLOW-OFF.

Name of Work.	Area of Catchment Basin.	Average Annual Rainfall.	Fall of River above the Dam	Estimated percentage of Flow-off to Rainfall.	Capacity of Tank.		Depth Allowed for Evaporation and Loss from all Causes.	Area Irrigable.	Cost of Works.	Cost per Million Cubic Feet Stored.
					Total.	Above Sluice Level.				
Tanks with Earthen Embankments.	Square Miles.	Inches.	Feet per Mile.	Per Cent.	Millions of Cubic Feet	Millions of Cubic Feet.	Feet.	Acres.	Rupees.	Rupees.
Mukti	34·2	20·9	21·3	25	342·4	342·3	7·0	—	2,67,400	781
Mhasva	13·4	22·5	21·4	33	160·9	158·6	3·0	1,700	69,900	441
Parsul	17·3	28·0	42·7	25	124·5	118·7	4·0	1,000	1,51,000	1,213
Sirsuphal	23·0	20·4	20·0	25	367·0	365·0	4·0	1,800	1,15,100	314
Matoba	10·0	15·2	32·0	25	230·0	229·0	4·0	3,250	1,20,767	527
Bhadalwadi	23·0	22·9	23·0	25	223·0	222·0	4·0	2,000	1,10,268	497
Pashan	16·0	—	41·0	—	80·0	73·0	4·0	—	1,67,200	2,090
Ekruk	159·0	31·6	8·5	25	3,330·0	3,310·0	7·0	16,941	7,78,300	235
Ashti	92·0	24·0	12·0	25	1,550·0	1,348·0	4·0	11,780	4,65,485	328
Pandharpur	10·0	27·9	21·7	25	89·0	79·0	5·0	—	1,07,700	1,210
Mhasvad	480·0	22·8	12·0	10	3,072·1	2,632·7	4·0	24,800	9,48,144	360
Nehr	59·5	28·4	25·2	25	522·6	489·7	4·0	5,480	2,84,932	582
Pingli	20·0	23·0	33·1	25	200·8	195·2	5·0	2,080	2,10,270	1,077
Maini	54·0	24·2	29·2	25	165·4	158·7	5·0	4,625	2,81,080	1,770
Medleri	11·0	21·5	33·5	33	62·3	57·6	4·0	600	47,400	822
Bhatodi	44·0	24·5	—	6	99·0	80·0	5·0	12,124	2,25,207	1,462
Dedargaon	14·0	22·9	38·8	25	124·8	118·0	4·0	—	93,700	751
Waghad (Lesser)	29·0	51·0	61·0	25	624·6	605·5	4·0	—	4,22,853	698
Pangaon	298·0	32·9	9·0	25	5,290·0	4,926·0	—	—	12,72,800	241
Gokak	1,080·0	55·0	2·4	—	701·6	701·6	3·0	—	5,45,600	778
Tanks with Masonry Dams.										
Lake Fife	196·0	—	6·0	—	4,911·0	3,833·1	4·0	16,800	26,38,193	866
Muchkundi	26·0	23·5	17·1	25	703·8	623·8	6·0	3,417	87,700	140
Chankapur	100·0	51·5	29·3	33	1,197·0	1,100·0	3·5	10,455	5,12,500	428
Bhatgarh or Lake Whiting ...	128·0	145·0	5·0	13	5,316·0	5,313·0	4·4	113,280	20,94,278	394

PRINCIPAL TANKS AND RESERVOIRS IN BOMBAY: DAMS, WASTE WEIRS—MAXIMUM DISCHARGE.

Name of Work.	Length of Dam.	Maximum Height of Dam.	Thickness of Dam at Top.	Height of Dam over Crest of Waste Weir.	Length of Waste Weir.	Height of Flood over Waste Weir Crest.	Discharging Capacity of Waste Weir.	Depth from full Supply Level to Sill of Outlet Sluice.	Description of Waste Weir.
Tanks with Earthen Embankments.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Cubic Feet per Second.	Feet.	
Mukti	3,000	65·0	10·0	13·0	1,590	5·4	32,265	41·0	Two masonry walls.
Mhasva	1,494	44·1	10·0	10·0	370	3·5	8,621	22.0	Masonry wall.
Parsul	2,770	62·2	6 to 8	10·0	560	4·0	12,800	35·0	Masonry wall.
Sirsuphal	2,188	54·3	4·0	11·0	300	5·0	18,000	31·0	Channel in rock.
Matoba	6,095	48·4	9·0	9·0	600	3·0	10,000	29·0	Masonry wall.
Bhadalwadi	2,590	55·0	6·0	11·0	550	5·0	20,000	35·0	Masonry wall and channel.
Pashan	2,750	52·0	6·0	10·0	400	4·0	11,000	21·0	Masonry wall.
Ekruk	7,000	76·0	6·0	17·0	540	10·0	43,763	38·2	Two channels in excavation.
Ashti	12,700	57·7	6·0	12·0	800	7·0	48,000	22·0	Excavated channel.
Pandharpur	3,500	44·0	4·0	11·0	200	4·5	5,944	18·0	Excavated channel.
Mhasvad	9,080	79·8	8·0	13·0	3,000	5·0	235,545 (?)	24·0	Concrete wall faced with masonry.
Nehr	4,820	74·0	8·0	13·0	700	6·3	38,720	32·0	Wall and channel.
Pingli	5,553	53·5	6·0	9·0	750	3·0	12,862	29·0	Concrete wall faced with masonry and excavated channel.
Maini	3,605	61·3	10·0	17·0	900	6·0	38,668	31·2	Masonry wall and channel.
Medleri	2,250	41·0	6·0	7·0	700	2·0	6,453	15·0	Masonry wall and excavation.
Bhatodi	2,316	50·0	5·0	7·5	450	3·0	15,192	22·5	—
Dedargaon	1,420	47·6	6·0	9·0	540	3·0	9,035	28·5	Excavated channel.
Waghad (Lesser)	4,060	96·0	10·0	13·0	357	9·5	18,725	38·0	Excavated channel.
Pangaon	15,100	76·8	8·0	16·0	1,500	10·4	192,307	30·0	Excavated channel.
Gokak	3,505	29·0	28·0	12·0	—	7·0	195,026	20·0	Concrete wall faced with masonry.
Tanks with Masonry Dams									
Lake Fife	3,687	106·7	9 to 14½	11·75	1,030[1]	5·0	74,877	28·2	Concrete and masonry wall.
Muchkundi...	421	60·0	6·0	6·7	500	5·7	16,600	23·3	Excavated channel.
Chankapur...	1,600	120·0	9·0	7·0	620	7·0	40,900	85·0	Masonry wall.
Bhatgarh or Lake Whiting	2,993	127·0	15·5	16·0	810[1]	8·0	56,457	83·0	Masonry wall, eighty-one openings, 10 feet wide.

[1] Clear length of sluice openings.

STATISTICS OF SOME OF THE TANKS IN RAJPUTANA AND CENTRAL INDIA :—

Name of Work.	Catchment Area in Square Miles.	Capacity in Millions of Cubic Feet.	Capital Cost in Rupees.	Cost per Million Cubic Feet of Capacity in Rupees.
Ajmere and Merwara :—				
Niaran	55·0	200	32,077	160
Nadi Nullah	12·6	50	4,563	91
Akhaijitgarh	8·0	105	775	7
Bhir	8·3	125	2,11,336	1,690
Foy Sagar	10·0	150	1,98,699	1,325
Barol	208·0	135	1,83,001	1,355
Khair	228·0	250	2,98,234	1,192
Jaipur :—				
Kalegh Sagar	227·0	578	2,81,262	486
Tori Sagar	320·0	2,057	6,23,631	303
Moran Sagar	35·0	567	1,74,200	307
Ramgarh	297·0	2,689	5,03,162	187
Jodhpur :—				
Bitara Tank	1,300·0	4,200	9,21,384	219
Dhontera Tank	800·0	3,220	4,27,924	133
Bharatpur :—				
Bareta Bund	70·0	1,360	3,23,654	238

CHAPTER VI.

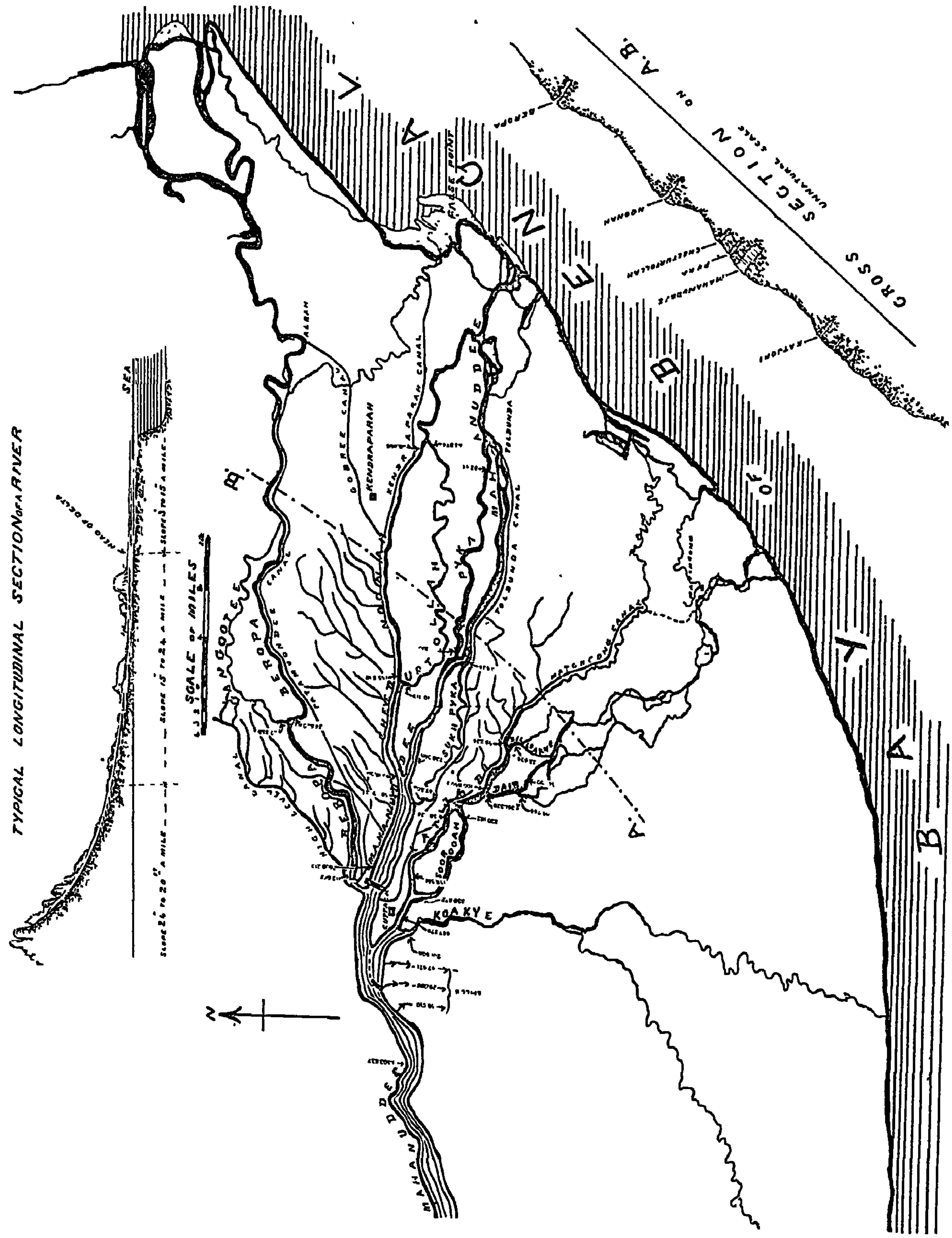
PERENNIAL CANALS IN DELTAIC TRACTS—EMBANKMENTS.

Formation of Deltas—The Mahanuddee Delta in Orissa—Decrease in Waterway in Deltaic Streams—Embankments necessary in Deltaic Projects—Limits to Embankments in Deltas—Increase in Flood-levels due to Embankments—Deltaic Tracts at Confluence of Rivers—Reduction in the Waterway of the Sone River as it approaches the Ganges—The Floods of the Gunduk—Drainage essential in Deltaic Projects—Embankments in Deltaic Tracts—Drainage due to Embankments—Effect of Embankments in increasing or decreasing Discharge—Disadvantages of Embankments.

THE canals of India which are drawn from rivers having a perennial supply of water may be broadly divided into two classes—first, canals which lie in the deltas of the rivers from which they draw their supply; and, secondly, canals which are drawn off from the upper portions of rivers before they assume a deltaic character. The canals of the first class are chiefly those of Madras and one or two in Bengal, while nearly all the canals of Upper India fall in the second class.

The delta of a river is usually spoken of as the tract of land, near the junction of the river with the sea, where it divides into two or more branches; but it would in some ways be better to define the delta as the land which has been formed by the inundations of the river. The slope of nearly all rivers decreases from their source to the sea: in the hills the river is a torrent; at its exit from the hills it may have, as the Ravi, the Ganges, and the Jumna do have, a slope of from 10 to 15 feet a mile; in the plains this slope is reduced little by little, until, near the sea, the slope may be as little as 3 or 4 inches a mile, as it is in the delta of the Ganges. The velocity of the streams in the higher parts, where the slope is steepest, is often too great for the soil, and the rivers cut into it, forming the *Khadir* and *Bhangar* lands which have been already described (page 10). In the lower reaches the velocity is greatly reduced and the river deposits the material, which it holds in suspension, in its bed, which is gradually raised by the process. The channel soon becomes too small for the flood discharge, and the water spills over the banks which are raised by the silt deposit. In some cases, such as the Godavery in Madras or the Mahanuddee in Orissa, there are indications that the sea, in prehistoric ages, extended to the hills which stand near the heads of the delta of these rivers, and that the land which now lies between the hills and the sea, has been entirely thrown up by them. The sketch on page 98 shows the general features of the delta of the Mahanuddee, which has an area of about 2,000 square miles between the Beropa and the Khoakye branches. The general level of the ground at the head of the delta at Cuttack is about 70 to 75 feet above the sea, and there is a fairly uniform slope in the land surface from that point to the sea. A great flood in this river has an average surface slope of about 0·25 per 1,000 in the delta. The great floods of this river attain to more than 1,500,000 cubic feet a second, and the amount of solid matter which is annually brought down must be very great (see page 36).[1] As soon as the river comes in contact with the ocean the waters spread out, more or less in a fan-like shape, and deposit the mud which they carry, until land is formed, which gradually rises above the sea level. Every succeeding flood spills over the low ground and raises it still further, depositing the greater portion of its silt near the channel of the river;

[1] "Report on the Floods of the Mahanuddee River," by R. H. Rhind, Esq., Bengal Secretariat Press.



DELTA OF THE MAHANUDDEE RIVER.

so the land, as it is raised, rises more quickly near the banks, and more slowly, the further the silt-laden water has to flow from the main current. The channel of the river is subjected to floods varying greatly in volume, and after a long series of low floods, which tend to restrict the waterway of the river, one of exceptional volume occurs, which, washing over the newly formed soil, cuts a fresh channel, or it may be two or three fresh channels, radiating from the point where the delta commences. These new channels become more or less permanent, and in their turn throw out silt into the sea, and form smaller deltas of their own, which amalgamate with and extend the dimensions of the fan-like submarine mound, which is continually being pushed out, as it were, into the sea. Hence it occurs that the branches, into which a river divides itself in its delta, are all more or less on higher ground, and that a section of a delta (see section on page 98) shows the channels on the ridges, the hollows between the ridges being sometimes found to be actually lower than the beds of the channels near them. The branches occasionally burst through their banks, and force new channels in the lower ground, which, in its turn, becomes raised by the silt deposits of the new channel. As the delta advances, the slope of the bed and surface of the river must become gradually less and less, for the length of the river increases and the level of the sea is constant.

A river, running in the soft soil of a delta, easily changes its course; the actual channels, as defined by the levels of the margin of their banks, are, from the nature of the method by which they are formed, not capable of carrying extreme floods, and the steady advance of the delta is always making them less competent to do so by reason of the continual decrease in slope. Consequently the relative dimensions of the main channel and branches are sometimes greatly altered. An alteration of this kind has been approximately gauged in the case of the Mahanuddee river. That river was subjected to extremely high floods in 1834, in 1855, and in 1872. In 1892 and 1896[1] there were again great floods, which attained the same height (92·10 at Naraj) as that of 1872, and the flood of 1896 was of longer duration than any. It has been calculated that, during the period which elapsed between the floods of 1855 and 1872, the carrying capacity of the Mahanuddee branch[2] had deteriorated to the extent of nearly 80,000 cubic feet per second, or 10 per cent. of its ordinary volume. So the relative importance of any branch is always liable to alteration in any great flood. The Plate on page 98 shows the approximate discharges, in the great flood of 1872, of the various channels, into which the delta of the Mahanuddee river is divided. The total discharge of the river above the delta was 1,503,627[3] cubic feet per second.

This volume is the entire flood which had to be ultimately carried to the sea, but it did not find its way to the sea entirely through the channels of the river: from 30 to 40 per cent. of the water was spilt over the banks of those channels, and ultimately passed to the sea through the low ground which lies between them. It was found that the total loss of discharge experienced by each principal branch of the river during the flood was as follows:—

—	Loss in Cubic Feet per Second.	Percentage of Loss on Original Discharge.
Beropa Branch	33,943	30·1
Katjori "	174,985	39·1
Mahanuddee "	232,897	35·9

[1] "Narrative of Principal Events connected with Flood Embankments in Orissa," by W. A. Inglis, Calcutta.

[2] Memorandum by R. H. Rhind, Esq., being No. 15 of "Papers relating to the Orissa Canals," Bengal Secretariat Press, 1884.

[3] "Report on the Floods of the Mahanuddee River during the year 1872," by R. H. Rhind, Esq., Bengal Secretariat Press, 1875.

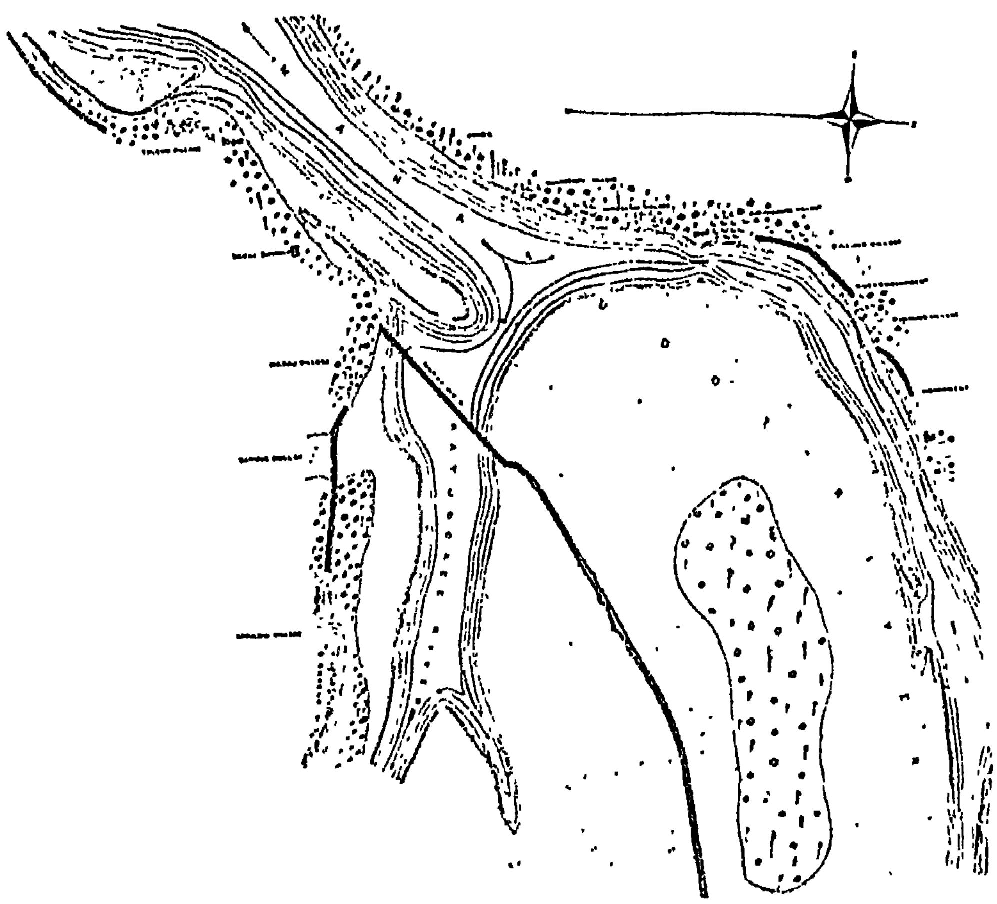
It is a common feature of deltaic rivers that the areas of the cross sections of the various branches diminish as they approach the sea. This is remarkably the case in the branches of the Mahanuddee, and the fact finds expression in the figures on the diagram on page 98, which give the discharges at the points indicated: it will be noticed that the discharge at the head of any particular reach of the river is always considerably more than the united discharges at the heads of the branches taking off at the lower end of the reach, showing that the waterway is insufficient to carry the entire discharge: this point is one of importance.

The delta of a river offers great advantages for irrigation: the soil is usually rich alluvium, the slope of the country from the head of the delta to the sea is always uniform and gentle: the slope transversely is also fairly uniform from the banks of the various branches to the natural drainages which lie between them: these drainages offer convenient means, when graded channels are opened through them, for discharging the surplus water: the fact that the river channels are on the ridges gives a comparatively easy command of the country. By throwing a weir across the head of the delta, and running canals along the margins of the branches, the whole delta can be irrigated. It is, however, generally necessary to construct a series of marginal embankments in connection with any delta scheme, for, as, in the nature of the case, the whole area under command of the canals is more or less subject to inundation, it is necessary to confine the floods to the river channels, or the crops in the low ground might be destroyed or damage might be done to the canals. To a considerable extent the canals would themselves form the marginal embankments, as they usually run on or near the banks of the rivers; but this would not always be the case. In designing a scheme of canals in a delta, with a system of protective embankments, consideration has to be given to the tendency of the river to change the allotment of its floods between the different branches, and it is usually, if not always, necessary to carefully regulate the discharge of the branches by weirs across both the main channel of the river and the branches also; the fact also of the reduction in the cross section of the branches as they approach the sea is of great importance in the design of the embankments, for a material increase in the flood-level will be obtained if the discharge of any channel is not only confined within it in its higher portions, where the usual spill over the banks may be considerable, but is further confined to the lower portions where the slope is reduced, and where the channel is also so reduced as to be incapable of carrying, between its banks, the discharge which the upper portions can bring down to it.

The necessity for the regulation of the discharge of the branches of a deltaic river is exemplified by the case of the Mahanuddee. It had been found that the head of the Katjori branch[1] (sketch on page 101), which takes off immediately below a gorge in the main river, was enlarging greatly after each year's floods, and that the increased volume, which was being drawn into it, was far greater than the lower reaches of the channel could possibly carry. The result was that there were extensive floods and destruction of crops; the embankments also which had been constructed to protect the country were unable to resist the increased pressure brought on them by the heightening of the flood level due to the increased discharge. At the same time the head of the main, or Mahanuddee, branch was found to be silting up, and that it was not carrying the proportion of the entire volume of the river which its general capacity enabled it to carry off. It was consequently decided to regulate the discharge of the Katjori by a stone spur which was constructed across the head of that branch in a direction diagonal to the course of the stream, and which ended in the high sand ridge which divides the channels of the Mahanuddee and the Katjori. This spur, which was of dry rubble roughly packed, was

[1] "A Short Sketch of the Scheme of Works proposed . . . in Orissa," by A. G. Crommelin, Esq., "Papers relating to the Orissa Canal," 1884.

completed in 1860, but it proved insufficient, and it was ultimately replaced by a masonry weir built across the stream of the Katjori, and strongly supported by an abutment on the Mahanuddee side, and a dividing embankment heavily revetted with stone. This weir has completely checked the enlargement of the Katjori and entirely separated the waters of the two branches. A similar instance of the necessity of controlling the branches of a deltaic river is found in the delta of the Cauvery, which commences near the island of Srirungum (see Plate on page 149). The main river divides at that point into two branches, the Cauvery and the Coleroon. The latter has a larger volume, a more direct channel, and more rapid slope, and the tendency was for the Cauvery to silt up, and for the whole stream of the river to pass down the Coleroon. This tendency was perhaps increased by the fact that the Cauvery, near the lower extremity of the island of Srirungum, was partially obstructed by the Grand Anicut, a work already referred to (page 13), which was constructed to assist the irrigation of the delta.



WEIR ACROSS THE KATJORI RIVER AT NARAJ

The first improvement effected was the construction of a weir or *anicut* across the Cauvery and Coleroon at the upper end of the island to regulate the discharge of the river between the two branches. Both in this case and in that of the Mahanuddee the construction of these regulating works was essential before it was possible to carry out the irrigation works, and to decide on the heights to which embankments had to be made to provide for confining the discharge of each branch within the limits of its own channel.

On the matter of embankments it has to be borne in mind that there may be a limit to which it is expedient, or even possible within any reasonable cost, to embank the branches of a river in its delta. The spill over the banks of the branches, and the diminution in the capacity of the branches as they approach the sea, may be so great that the height of the necessary marginal embankments becomes prohibitive. In order to determine how far embankments can be carried, and what the height of them should be in any particular case, it is necessary to survey all the branches, to cross-section them at frequent intervals, to record the actual levels in high floods, to record the varying surface slopes, and to calculate from these data the discharges at all the important points. It is further necessary to determine the probable maximum flood which may occur (for it is rarely that such a flood will occur during the investigation) and to estimate how this flood will be divided among the branches, either by

nature, or by the works which will probably be found necessary, in order to apportion the total volume, in the most practicable way, according to the relative capacities of the branches. Then, having fixed the allotment of each branch, the discharge has to be followed down the channel and its ramifications; the discharge, in any reach, being divided proportionately between the two (or more) channels which may flow from it: in this way the whole discharge of the river will be marked out on a rough chart. It is then necessary to ascertain the surface level of the water which it will be necessary to have in each channel in order that it may be capable of carrying the discharge allotted to it in the chart. This has to be done more or less by a system of trial and error, assuming, in the first instance, surface slopes about the same as those which originally existed. The process is extremely laborious, but the engineer will soon convince himself that it is absolutely necessary before any system of canals and embankments can be laid down in a delta with a reasonable prospect of security, for he will soon find that the discharges which he is theoretically heaping on to the channels, which become more and more restricted as the quantity increases, will raise the water surface to a dangerous extent, and he will be compelled to either open up entirely new channels or to abandon his embankments, on certain tracts, and allow the flood access to the lower ground which lies between the branches. This has been found necessary in the delta of the Mahanuddee river; one large escape, 850 feet long, capable of discharging 30,000 cubic feet a second, has been built on the Bhargori river, and others are to be built—two on the Khushbadra to take 10,000, and two on the Daya to take 25,000 cubic feet per second each.

It will generally be found, too, in an extensive delta, that, just as regulating weirs were found necessary at the head of the delta to distribute the discharge, so they will be found necessary lower down to divide it to the best advantage among the smaller ramifications.

A survey and investigation of this nature has been made of the River Mahanuddee[1] and its delta; this showed, as has already been stated, that the joint capacity of the various channels forming the outlets of each branch was only about 60 to 70 per cent. of the capacity of the head of the branch, and that the volume of water, which spilt over the banks of the channels at various points, aggregated about 600,000 cubic feet a second, and that 1,000[2] square miles of country were inundated. A scheme was worked out on the following basis:—

Branch.	Discharge at the Head of each Branch in Flood of 1872, in Cubic Feet per Second.	Proposed Discharge to provide for Maximum Flood.
Barung River and Spills above Cuttack ...	132,547	*Nil*
Mahanuddee Branch	609,213	954,000
Beropa "	112,662	112,000
Koakye "	201,936	45,000
Katjori "	447,279	460,000
Total	1,503,637	1,571,000

It was proposed to reduce the discharge of the Koakye branch on account of the damage done by its floods, and a corresponding increase was allowed in the main Mahanuddee branch as its capacity was sufficient. It was shown that, if a comprehensive system of embankments

1 "Report on the Floods of the Mahanuddee River," by R. H. Rhind, Esq., Bengal Secretariat Press, 1875.
2 "Papers relating to the Orissa Canals," page 50. Bengal Secretariat Press, 1884.

were constructed to pass these quantities, without spill, the flood level would be raised approximately as follows in the upper reaches of the branches:—

Branches.	Number of Feet by which the Surface Level of the Flood would be raised above that of the Flood of 1872.		
	From		To
Mahanuddee Branch—			
From weir to head of Sook Pyka	3·79	...	5·87
" head of Sook Pyka to Cheerturtollah ...	5·25	...	—
" head of Cheerturtollah to outfall of Pyka...	3·68	...	6·60
Beropa Branch—			
First reach	0·00	...	5·87
Koakye Branch		reduced	
Katjori Branch—			
From Cuttack to head of Sooroaah	0·41	...	0·46
" head of Sooroaah to outfall of same ...	1·21	...	4·48
" outfall of Sooroaah to head of Daib ...	2·95	...	3·17
" head of Daib to head of Belloakye... ...	2·52	...	5·16

The resulting velocities varied from 3·23 to 4·19 feet per second. The calculations were carried further forward into the smaller branches, and it was found that the flood levels would increase to prohibitive heights in certain places. It was consequently proposed to leave certain tracts, aggregating some 200 square miles in area, unprotected, and to let them be open to inundation from the river, so as to decrease the volume thrown upon the lower channels of the branches. A concrete example of this kind shows the necessity of care in dealing with delta projects: an increased flood level of 5 feet is a serious matter in the case of a breach in an embankment. The damage done by a breach in an embanked river is far greater, in the area immediately affected by the breach, than that which occurs from the spills which would ordinarily flow over the country at the same place if the river were not embanked.

Any system of embankments, it must not be forgotten, is subject to the disadvantage that it stops the deposit of the silt which the floods carry over the flooded area and leave upon it, and it thus interferes with the action of Nature, which gradually raises the level of the land by many successive deposits, each of inappreciable amount.

The action which takes place at the junction of a silt-laden river with the sea occurs, also, in some cases, at the confluence of two rivers. This action has occurred at the confluence of the Sone river in Bengal with the Ganges, and, in a less marked degree, at the point where the Gunduk and the Gogra join the Ganges. These three tributaries of the Ganges run, more or less, on raised ground, and there are spill channels from them, which are on slight ridges also. In these cases it is now only on rare occasions that the tracts, which may be called the deltas of these rivers, are inundated. In the case of abnormally high floods spills do occur from these rivers, and the land, near the confluence of the rivers with the Ganges, are inundated, just as the delta of the Mahanuddee is. In the case of a great flood in the Sone river in 1876, it was found that the discharge of the river 70 miles above its confluence with the Ganges was 830,000 cubic feet per second, while 20 miles above the confluence it was only 560,000 cubic feet. The difference between the two volumes was spread over the delta. So the Sone is similar to the Mahanuddee in that the river channel itself is not able to carry off more than about two-thirds of a maximum flood.

The Gunduk river used to spill largely over both its banks: the spills on the west side have been entirely prevented by a line of embankment which extends continuously from the mouth of the river up to a point above the heads of the four "nuddees," or spill channels, of a deltaic character, which traverse the country. On the east side an embankment has also been constructed, but it is not continuous: an opening is left at the head of the Byar Nullah through which a large volume passes in floods, and there are other large openings in the embankments which afford considerable relief to the river at these times. The embankments are frequently pierced by sluices through which water is at times drawn from the river when in flood, for the irrigation of rice crops in the low ground. On the western side of the river the Sarun Canal has been excavated, by which a certain amount of water can be supplied into the four "nuddees" at certain times of the year; as these channels are on slight ridges the water can be drawn out on to the lower ground by cuts through the banks of the streams. The Sarun Canal is, however, now hardly ever used. There is unfortunately very little information available as to the discharge and volume of spill from the Gunduk, but the deltaic character of the country on the west bank is clear, and the utilisation of the old spill channels as canals for supplying water for irrigation is interesting. The Gogra river also spills largely in years of very high floods over both its banks near its confluence with the Ganges. It is very probable that in both the Gogra and the Gunduk the waterway of the channels decreases as they approach the Ganges, but this has not been proved to be the case as it has been in the case of the Sone. There is some evidence that the bed of the Gunduk river is rising in consequence, probably, of the marginal embankments. The record flood in the river occurred in 1883, when the embankments were topped in many places and they were subsequently raised. In 1903 a flood occurred which reached the same height as that of 1883 at a point above the embankments. The embankments, which were 3 feet above the level of the 1883 flood, were again topped, although the volume of the flood was not, it is believed, in excess of that of 1883. This seems to show that the bed of the river must have been raised in the interval between the two floods.

The chief crop grown on all deltaic tracts in India is rice. This crop requires a large volume of water, and it benefits by a constant change of water, so that the cultivators, when they get the opportunity, will drain and refill the fields as much as they can. This is one reason why drainage works are more necessary in connection with deltaic irrigation systems than in others. The alignment of these drains is generally simple, as there are usually well-marked hollows between the ridges in which the drainage cuts are properly placed, but it is sometimes difficult to find an efficient outfall which will not silt up by the tidal action to which it is probably exposed.

In the previous pages the necessity for embanking the margins of the natural channels in deltaic tracts, before any effective system of irrigation can be developed, has been pointed out. Such embankments, however, although essential, are by no means without disadvantages, which in some cases are of considerable magnitude. Any deltaic tract is, more or less, in course of formation: the land in it has been the result of the deposits of untold ages, and the fact that embankments are necessary to protect the land from floods, is a proof that it is still being raised by the action of the river. By embanking the channels and thus depriving the land of the yearly deposit its growth is stopped. In the higher portions of a delta this is perhaps of little importance, but there are cases, more particularly where the lands are within tidal influence, in which the result of embankments is disastrous. The immediate result of an embankment near the margin of a river or tidal channel, which carries water laden with silt, is, that the land lying between the embankment and the stream—which is often of considerable width—is raised by the annual deposit more quickly than it would otherwise be, while the land

within the embankment is not raised at all. In some cases, especially within tidal influence, the beds of the channels are raised simultaneously with the banks. The process is often extremely slow and inappreciable, but in other cases this is not so. The result is that the embankments have to be raised, from time to time, to resist the increased flood level of the stream, and the dangers due to a breach of them become aggravated. The land lying in the protected area is drained, when the embankments are first made, with comparative ease, through the local drainages which are provided with sluices into the main channel; but as the banks and bed of this channel are raised the drainage of the lands becomes more and more difficult and expensive.

In some cases in the Midnapore district of Bengal, it is recognised that the only possible way of draining certain embanked tracts in which this action has been going on, would be by dredging the deposits from the streams, or by making drainage channels with outlet sluices actually on the sea face.

Embankments which are constructed to protect low-lying lands from inundation have the effect of decreasing the maximum discharge of the neighbouring channels if they are purely or mainly tidal estuaries (or *khalls*), and they have the effect of increasing the maximum discharge of rivers which lie above the action of the tides. An embankment confines to the river that portion of the water which would otherwise flow over the land; hence, when the water is coming entirely from above (as in the case of a river above tidal flow) the discharge, at and below the site of the embankment, is increased, as the water, which might have been distributed over the land is compelled to pass forward at once. But the case is different in a purely tidal channel which receives little or no drainage water from above; in that case the embankment reduces the amount of water which flows up the channel at flood tide by the quantity which would have spilt over the country had there been no embankment, and, consequently, at ebb tide, the receding flow is also reduced. In these cases the low-lying land is a reservoir which receives and discharges, more or less, at each tide, a definite volume of water: when the land is reclaimed by an embankment this action ceases and the flow in the tidal channel is reduced. When this reduction of discharge occurs the tidal channel very rapidly accommodates itself to the circumstances and silt is deposited in large quantities. In deltaic tracts there are channels which are purely tidal and receive little or no drainage water from above; there are others which, lying within tidal limits, flow during a great portion of the year almost entirely by tidal influence, but, in the rainy season, are called upon to discharge large volumes brought upon them by drainage from the plains above. It is in these channels especially that embankments are works which produce unexpected results; the discharge of drainage varies greatly, and there are often long periods of years during which the discharge may be moderate: during these years, when the low grounds are embanked and the purely tidal flow is checked, the tidal outlets of a large river deteriorate in capacity. When, subsequently, a year of heavy rainfall, and, consequently, of heavy upland floods occurs, the reduced channels are overloaded and breaches are inevitable.

Independently altogether of the injury which embankments may effect, by impeding the natural accretion to the soil which inundation produces and by causing the deterioration of channels, there is the fact that the protection of a tract from inundation is not in itself an unmixed blessing: inundations from silt-bearing rivers, although they may and often do injure the standing rice crop, are at the same time very advantageous to the lands from the manure they leave behind them, which improves the cold-weather crops greatly. It is not an unusual event to find lands on the river side of an embankment, and which are therefore subject to inundation, realising higher rents than the protected lands within the embankment. The

rich deposits in the first case more than compensate for the risk of damage to which the crop is liable.

In the upper reaches of most rivers, and particularly in Bengal, there are tracts of land which are subject at intervals of ten or fifteen years to extensive inundation due to unusual floods brought down by the rivers above them. These tracts act as compensation reservoirs for these unusual floods, impounding the surplus waters for a time until the river channels below can find leisure to carry off the surplus. Many of these tracts are slightly embanked, and agitation for the complete protection of them is periodically made after unusual inundations. Those who are interested in the entire protection of these areas fail to realise that the embankment of each tract increases the difficulty of protecting the one below it, and that when embankments are commenced in the upper reaches of a river and the surplus waters are compelled to flow forward, it is essential, if equal protection is to be given to all, to carry the line of embankment unbroken to the sea. It is now beginning to be realised by some engineers and officials in Bengal that embankments on the margin of silt-bearing rivers in deltaic or quasi-deltaic tracts may be a source of difficulty and even of danger: on the Damooda river, on the Goomtee, and on the Ganges considerable lengths of embankment which were originally constructed to prevent the spills of the rivers, have been deliberately abandoned mainly to relieve the congested channels of the rivers. In several other cases also proposals are being made to remove embankments which are known to be dangerous to the lives of the residents in the "protected" area.

CHAPTER VII.

GENERAL NATURE OF HEAD-WORKS.

Purposes of Head-works—Influence which Silt has with reference to Site and Design—Oblique Weirs and those at Right Angles to the Axis of the Stream—Head-works in Deltaic Tracts—Old Weirs—The Grand Anicut in Madras—Classes of Indian Weirs—Dangers to River Weirs—Onward Flow of the Materials forming the Bed of a River—Increase of Level of River Beds above Weirs—Sluices inefficient to check Deposits above Weirs—Currents induced by Accretions in a River Bed above a Weir—Parallel Currents along the Face of Diagonal Weirs—Retrogression of Levels.

One of the most important matters to be settled in connection with any irrigation project is the proper site and the nature of the head-works. These include the weir across the river, the under-sluices in the weir, the head-sluices of the canal, and, if the canal is to be navigable, the head-lock from the river to the canal. It is not, in all cases, necessary to construct a permanent weir. It may be possible, as in the case of the Ganges Canal, to divert the water from the river to the canal by means of temporary spurs constructed right across it when the river is low, or thrown out for some distance into it when it is not necessary or possible to draw off the entire discharge; or it may be possible, as in the case of the Trebeni Canal in Bengal, to place the head-sluice above a natural barrier in the river bed which will fulfil the functions of a weir. But these methods are generally only practicable when the river is a shallow one and the banks low, as otherwise the canal would have to be in very deep cutting; and they can only be employed where the bed of the stream is narrow and either in boulders or rock; in broad rivers with sandy beds the annual cost of the spurs would be very great, and it would be impossible to construct them in time to ensure a constant supply. The main objects of a weir are to raise the level of the water in the dry season, when the river is low, and to provide a means of forcing it through the head-sluices of the canal: the under-sluices, which are openings in the weir itself, are necessary to create a scour, during the flood season, to keep a definite channel open above the weir in the neighbourhood of the canal head, so that there may be no difficulty in leading the water to the head-sluices when the river is low.

The selection of the site of the head-works is often a matter of considerable difficulty. The problem is generally to find the best site for a weir on a given river in order to command as large an area as possible, but it may be to select a site for a weir to command a particular tract of country. In either case one of the most essential points to be first considered is the nature of the silt carried by the river: whether it is fertilising or the reverse: what proportion of it it is desirable to carry down the canal, and whether the soil, in which the canal is to be cut, can stand the velocity which will carry the silt. When the slope of the canal is determined an idea can be obtained, from the levels of the country, of the point where the water from any point of the river can be delivered on the surface of the ground, and the area under command of different sites can be ascertained. The approximate lengths and depths of cutting of the unprofitable portion of the canal, which lies between the head-works and the first point of irrigation, can also be roughly worked out, and it is necessary to do this, as the cost of this portion may often be very great. The height of the weir above the bed of the river should next be determined: this will depend on the depth of water in the canal and the level of the canal bed with reference

to it; here again the important question of silt deposit must be borne in mind (see pages 38 to 40): if it is feared that there will be much difficulty with silt it is desirable to keep the under-sluice floor as low as possible and the canal bed as high as possible, a combination which results in a high weir, and it has to be considered whether the cost of foundations may not be unduly enhanced if the under-sluice floor is depressed. Then the effect of weirs of various heights on the flood level of the river should be worked out: the flood discharge must be ascertained from gauge readings, from cross sections of the river and known surface slopes, and from these data the depth on the crest of the weir which will be necessary to discharge a maximum flood can be ascertained, and hence the afflux or height by which the flood will be increased by the weir. This point is of extreme importance, as upon it depends the necessity for constructing embankments to control the river above the weir: if the afflux is great the country above the weir may be inundated and there may be a danger of the flank of the work being turned by the river. In light sandy soils this might result in the river cutting out another course for itself and leaving the weir at a distance from the new channel of the river. This difficulty may be avoided by constructing a comparatively low weir and placing folding shutters on the entire length of the crest which can be raised in the dry season and depressed in the floods to allow of the free discharge of the flood waters. This method is one which has been more generally adopted in recent years, and it possesses many advantages. Another point which requires consideration in the selection of the position and design of head-works is whether the weir should be placed at right angles to the course of the stream or inclined at an angle to it. In deltaic systems where the soil at the site of the weir is friable, and in all cases where the bed of the river is light sand, it is essential that the weir should be at right angles to the stream, for a skew weir would induce parallel currents which would scour in front of the weir and probably undermine it: but on rock, and in the boulder beds of rivers near the hills, a weir on the skew may frequently be constructed with the advantage that a better control over the cold-weather channel is obtained, for the main current of the river is directed toward the under-sluices and a powerful "draw" is obtained which tends to keep the cold-weather channel open. Weirs at an angle to the stream have been constructed on the Jumna river, at the head-works of the Western Jumna Canal (Plate on page 127), and on the natural channel which forms the main feeder of the Eastern Jumna Canal, where the soil is largely composed of boulders. On the Bari Doab Canal, which takes off the Ravi river at a point where the slope is more than 20 feet a mile, the weir was built square across the river, and a great deal of difficulty has been encountered in maintaining a channel to the head-sluices of the canal. The bed of the river has filled up to the weir crest with boulders, and the cold-weather channel is controlled with difficulty: this would probably have been avoided to a great extent if the weir had been at an angle to the course of the stream.

The most suitable position, as a rule, for a weir and head-works of a canal is on a portion of the river where the channel is straight, the velocity uniform, and the sectional area of the stream fairly constant. A narrow gorge of a river appears to have the advantage of cheapness, but it may be the most expensive on account of the greater velocity and greater depth of the water, which produce a stronger action on the weir, and necessitate heavier materials or stronger work. A particularly wide reach of a river has, on the other hand, the disadvantage that, the average velocity being decreased, the deposit of silt and sand is encouraged, and the bed of the river above the weir is likely to become so raised that it may be difficult to keep a channel open to the head-sluice of the canal. The nature of the soil on either side of the weir for some miles above it has to be examined: it is important to choose a site where the river shows no signs of changing its course, or expensive training works may be required. Another

point of importance is to select a site as near as possible to a supply of stone for constructing the weir if there be any in the neighbourhood: the lead of building materials is an important factor in the cost.

In the case of irrigation projects in deltaic tracts there is usually but little option in the selection of a site for the head-works: if the areas lying between the various branches are to be irrigated, the weir must necessarily be at the point where the branches leave the main stream.

There is no country where the art of constructing weirs across large rivers has been more deeply studied or so successfully practised as India. India can show the longest weirs in the world, and, with one or two exceptions, the highest ones. The construction of weirs of moderate height was successfully accomplished by natives long before English engineers came to the country to benefit by their experience, and to improve on their methods of construction. The Grand Anicut on the island of Seringham in the Tanjore district of Madras is a notable example of a native work which has successfully stood the test of time. That weir is 1,080 feet long, and from 40 to 60 feet in breadth; the crest is 15 to 18 feet above the bed of the river.

This old work was built in a serpentine form across the bed of the Cauvery river; the natives who constructed it probably held the theory that it would be stronger in that form, as the channels of natural streams generally take that shape. The surface of this weir was originally intersected by rough channels at a lower level than the general crest: these were probably intended to act as rough under-sluices. It was not until the year 1830, when permanent under-sluices were constructed in this weir by English engineers, that it was discovered that the old weir, which is said to have stood successfully for 1,600 years, was only composed of rough stones set in clay, and that no mortar of any kind, as had been supposed, was used in its construction.

The earlier examples of weirs constructed by natives are mostly those in which only boulders and large stones were thrown together to form the main body of the weir, the front slope of the weir and the crest for a short distance being hand packed. In some cases the crest stones were bound together by iron dogs. There are, however, some samples of weirs constructed by natives in masonry. There is also at least one example of a composite one, built on rock, the up-stream face being of brick masonry, the down-stream one of coursed rubble, the core of concrete, and the crest of granite ashlar.

There are six main classes into which Indian weirs may be divided:

1. Weirs founded on rock.
2. Weirs in the boulder formation in the higher portions of rivers near the hills.
3. Weirs in clay or hard kunkur soils.
4. Weirs on sand of moderate depth with clay or rock below.
5. Weirs on coarse sand of great depth.
6. Weirs on fine micaceous sand of great depth.

Weirs of the first two classes are usually on rivers with a declivity of from 25 feet to 5 feet in a mile; those in class 3 on rivers with a slope of 6 feet to 2 feet in a mile; and those of the other three classes on rivers having a slope of 2 feet to as little as 4 inches in a mile.

There are several well-known dangers which threaten all river weirs. There is, first, the danger of the weir being breached by the actual force of the current sweeping the materials of the structure away. Breaches may, in this way, be caused by the "pound" of the water falling on the floor of weirs having a vertical drop, or by the actual friction of the water passing over the materials forming the slope or talus below the crest, or by the velocity of the water carrying away the bed of the river below the weir and thus undermining the structure

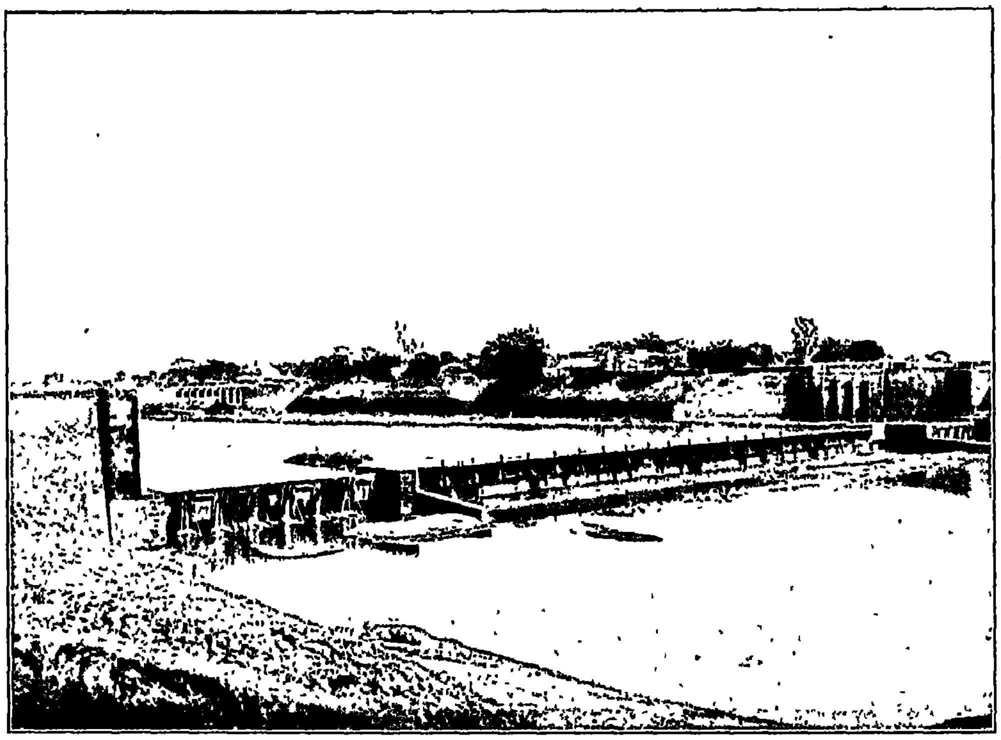
from behind. This danger is most common in the case of rivers having a rapid fall and subject, consequently, to rapid floods. A rapidly rising flood is more dangerous than one rising slowly, not only by reason of its greater velocity, but from the fact that the rapidly rising flood causes a greater head on the weir, that is a greater difference in level between the water above and that below it: the river bed has in that case less time to fill up and so form a "cushion" to protect the rear slope of the weir. A rising flood, be it a rapidly rising one or not, is always more dangerous than a falling flood, for the same reason. The breaching of weirs by the action of the water flowing over them is common to all classes of weirs, and it most commonly occurs by the undermining of the weir from below. This danger is to be guarded against by long floors or long tail slopes, and by the use of sufficiently heavy blocks of stone where the velocity is great.

There is, secondly, the danger that a weir may be "blown up" by the water pressure below it. This is a danger which threatens all weirs with impervious floors. If the core wall of the weir, or the upper slope of the weir above it, is not made sufficiently water-tight to resist the head of water retained by the weir, the hydrostatic pressure below the floor of the weir may be sufficient to lift the masonry and breach the weir. This occurred in the Narora weir at the head of the Lower Ganges Canal (page 161).

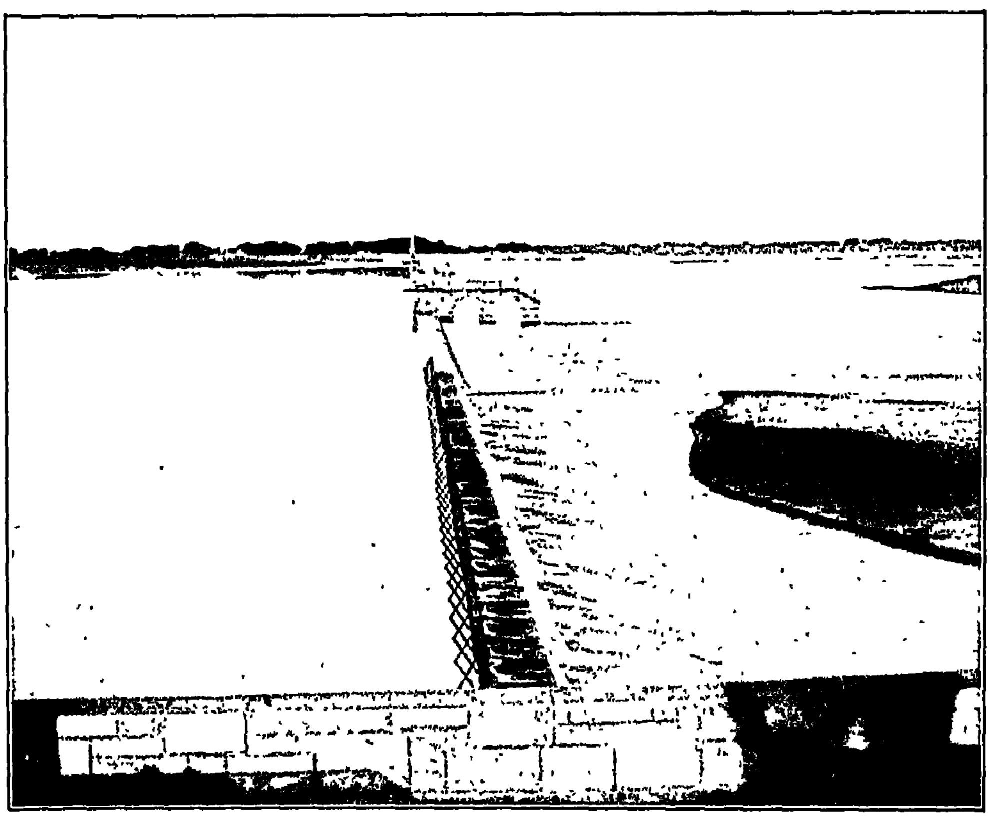
A third danger to which river weirs are exposed is that of being breached by water flowing below them and undermining the foundation. This danger is not a common one in India, as the head of water on the weirs is small, and the river beds above the weirs frequently silt up nearly to the crest level, and the flow, immediately below the masonry, is reduced to a minimum by the staunching of the sand by the muddy silt. But the breach in the Orissa weir (page 144), and the subsidence of the Chenab weir (page 169), were both due to leakage and "piping" below the foundations of the weirs. Weirs of the last three classes are more or less liable to be breached in this way; those of the last class are the most liable: the danger may be met by curtain walls sunk into the river bed below the general foundation level of the weir, by sheet piling, or by laying a puddle floor of clay under the upper slope of the weir above the core wall (page 169); or it can be stopped, even in weirs with shallow foundations, by increasing the width of the weir so that the frictional resistance to the flow of the water through the sand below it is increased.

A fourth danger is that a weir may be outflanked by the water in the river. This is most likely to occur in rivers with friable banks, and especially when the course of the river above the weir is not straight and shows signs of change. It is desirable in those cases, where there is any probability of the river seeking to change its course, to keep the weir as low as possible, so that the afflux caused by it may be small. This danger is to be met by training works above the weir: these, in some Indian weirs, are of very considerable extent.

A fifth danger to which weirs across large rivers are subject, is that of parallel currents. These currents generally threaten the front face of a weir; they tend to undermine the foundations, and thus breach the weir. They are generally due to the formation of islands in the bed of the river, which are caused by the gradual advance of the river bed itself and by the deposit of silt in the pond above the weir, where the velocity of flow is checked. There are few rivers, other than those in absolute rock, where there is not a more or less constant flow of the materials forming the bed of the river. In a river with a sandy bed this action is in some cases visible. As the water flows, so the bed flows, but more slowly. The grains of sand may be seen travelling forward when the velocity is sufficient to move them, and grain by grain the whole body of the river bed is slowly and intermittently advanced with the varying velocities of the stream.



PANCHKOORAH WEIR, MIDNAPORE CANAL



NARORA WEIR AT THE HEAD OF THE LOWER GANGES CANAL.

[*To face page* 110.

The same action is not only visible, but is actually audible, in rivers in the boulder formation: in these rivers the flow of the boulders in a heavy flood may often be plainly heard as the stones pass over the floor of the under-sluices of weirs. In some cases it has been found necessary to cover the noses of piers in these rivers with timber to protect them against the constant blows of the boulders. When a weir has been constructed across a river it acts as a bar to this forward motion of the river bed, and gradually the advancing sand or shingle rises to the level of the crest, or even above the crest of the weir. The Plate on page 149 shows this result in the case of the upper Coleroon weir in Madras, where the river bed has been raised in a very marked manner. This weir is in two lengths: the northern one is 393 feet long and 7 feet high, and the southern one 1,736 feet long and 5 feet high. There is a series of sluices at frequent intervals in this weir—the northern weir having a central set of 48 lineal feet, and the southern weir six sets of sluices of 111 lineal feet: the waterway of the sluices is about one-twelfth part of the obstruction offered by the weir. But these frequent sluices have not impeded the rise of the river bed, and have produced little effect except that local channels have been cut through the sand above the weir down to the level of the floor of the sluices. It is believed that there are few instances in which a weir has been pierced at such frequent intervals: but there are many instances in which it has been proved that the scouring effect of even the most powerful sluices is comparatively small, in checking the general rise of the bed above a weir. Such sluices will maintain a channel through the deposits above the weir in their immediate neighbourhood, and this channel may run back a sufficient distance to enable the low level supply of the river to be drawn into it. But the only certain way of constructing a weir which will not raise the bed of the river above it is to keep the crest low and to raise the level of the pool in the dry season, by shutters, or needles, or a movable dam of some kind on the crest of the weir. This system is now in most cases adopted in Upper India, and the Madras engineers have accepted, generally, the same principle. Indeed, in that Presidency, large gates of great span have been largely used. Shutters have been erected of all sizes up to 40 feet span and 12 feet in height (page 194). There are great advantages[1] in the use of large shutters, as the *régime* of the river is not interfered with as much as when small shutters, standing between piers, are used. It is found in Madras that by manipulating these shutters the bed of the river above a weir can be regulated in a surprising way, shoals and accretions being swept away. There is no doubt that, for under-sluices, the system of heavy gates lifted vertically is in almost all cases the best one, but it is thought that for shutters along the crest of a weir the system used on the Chenab Canal (page 170), is preferable to the Madras one. In those cases where canals take off on both banks of a river above a weir, and it is desired to maintain a navigable channel between them, the silting of the river above the weir may seriously impede navigation. It has done so in the case of the Sone weir in Behar almost entirely, and to a smaller extent in the Mahanuddee in Orissa. But a more serious result is that the gradual raising of the bed may interfere with the supply of the canal in the dry season; for, as the deposit above the weir increases, the effect of the under-sluices in maintaining a deep channel through those deposits becomes less and less effective. The channel will always be kept clear to the level of the floor of the under-sluices in their immediate neighbourhood, but the bed of it may be so raised, some distance above the weir, as to interfere with the discharge in the dry season. It will then be necessary either to dredge this channel or to raise the weir crest temporarily. The plan of raising the weir crest by shutters,[2] which are put up in the dry

[1] Note by Mr. A. T. Mackenzie, dated Aug. 1st, 1904.

[2] Such shutters have been erected on the weirs which supply the Sone Canals, the Sirhind Canal, the Orissa Canals, the Lower Ganges Canal, the Betwà Canal, and in several other cases, on weirs which were not in the first instance designed for them.

season, and laid flat on the weir crest in floods, has been adopted in several cases in which it had been originally supposed that the level of the crest of the masonry weir would have been sufficient to have ensured the supply. If the raising of the river bed above a weir were uniformly distributed along the face of the weir, there would be no disadvantage in it as regards the stability of the weir, but this rarely or never takes place. The bed fills up unevenly and sometimes a main channel is left, which is so narrow that a high velocity is induced in it which is injurious to the weir at the point where the stream impinges upon it.

The accretions in the bed of a river above a weir, are not, as a rule, uniformly distributed. The currents of the river vary in intensity and direction in different stages of the floods, and they carve out channels in the moving bed: between these channels, islands gradually rise on which grass and brushwood take root in the dry season. This vegetation checks the velocity of the next flood, and silt is deposited, year after year, until the island rises up to, or nearly up to, the highest flood level. In the river bed above the Sone weir in Behar, there are many such islands which are 8 or 10 feet above the original level of the river bed, and which are regularly used for pasturing cattle. The islands which are formed in this manner become sufficiently stable to influence the flow of the river, and they may be so disposed that, more especially in falling floods, they may cause currents parallel to the face of the weir, which, if not stopped, may be dangerous. It is frequently necessary to throw out stone groins at right angles to the line of the weir to check such parallel currents.

It must not be assumed that the silting up of the bed of a river is the invariable result of the construction of a weir. There are instances to the contrary, more particularly if the weir is situated in a narrow gorge of the river where an increase occurs in the velocity of the stream. The velocity above, and over, the weir may then be sufficient to prevent any deposit. Generally speaking, it may be said that the bed above a weir in the boulder formation, or where the bed is of coarse sand, is almost certain to be raised up to, and even above, the weir crest. But the finer the sand and the more muddy the silt in the river, the less likelihood is there of a rise in the bed above the weir.

Dangerous parallel currents may be induced in front of a weir by a faulty alignment of it. In almost every case, as has been already stated, a weir should be placed at right angles to the axis of the river on which it is built, unless it is on rock or in the boulder formation. This should invariably be done where the bed of the river is liable to erosion. A weir set diagonally across a river is obviously liable to be exposed to a parallel current along the upper face; for the water impinging on the diagonal face will be diverted towards the lower end of the weir. A weir built on rock may withstand this action, but in other cases it is dangerous. In the case of the Naraje weir in Orissa (see sketch, page 101) which was built diagonally across a river with a hard sandy bed, it was found necessary to protect the weir wall, at considerable expense, by immense masses of rough stone thrown on the up-stream side of the wall: the weir wall has, on more than one occasion, been undermined by the action of the parallel currents and the piers of the under-sluices have been completely overthrown, possibly by the same force.

Another of the dangers which threaten some river weirs, and which may be a serious one, is that of a retrogression of levels in the bed of the river below the weir. It has already been explained (page 97) how, in certain portions of a river's course, after it has emerged as a torrent from the hills, the velocity of its waters is too great for the soil, and an action is constantly going on which gradually deepens the level of the bed, and reduces the surface slope until the velocity is suitable to the soil in which the river flows. A weir constructed across a river in which this action is in progress stops the erosion above the weir by forming a permanent bar at that

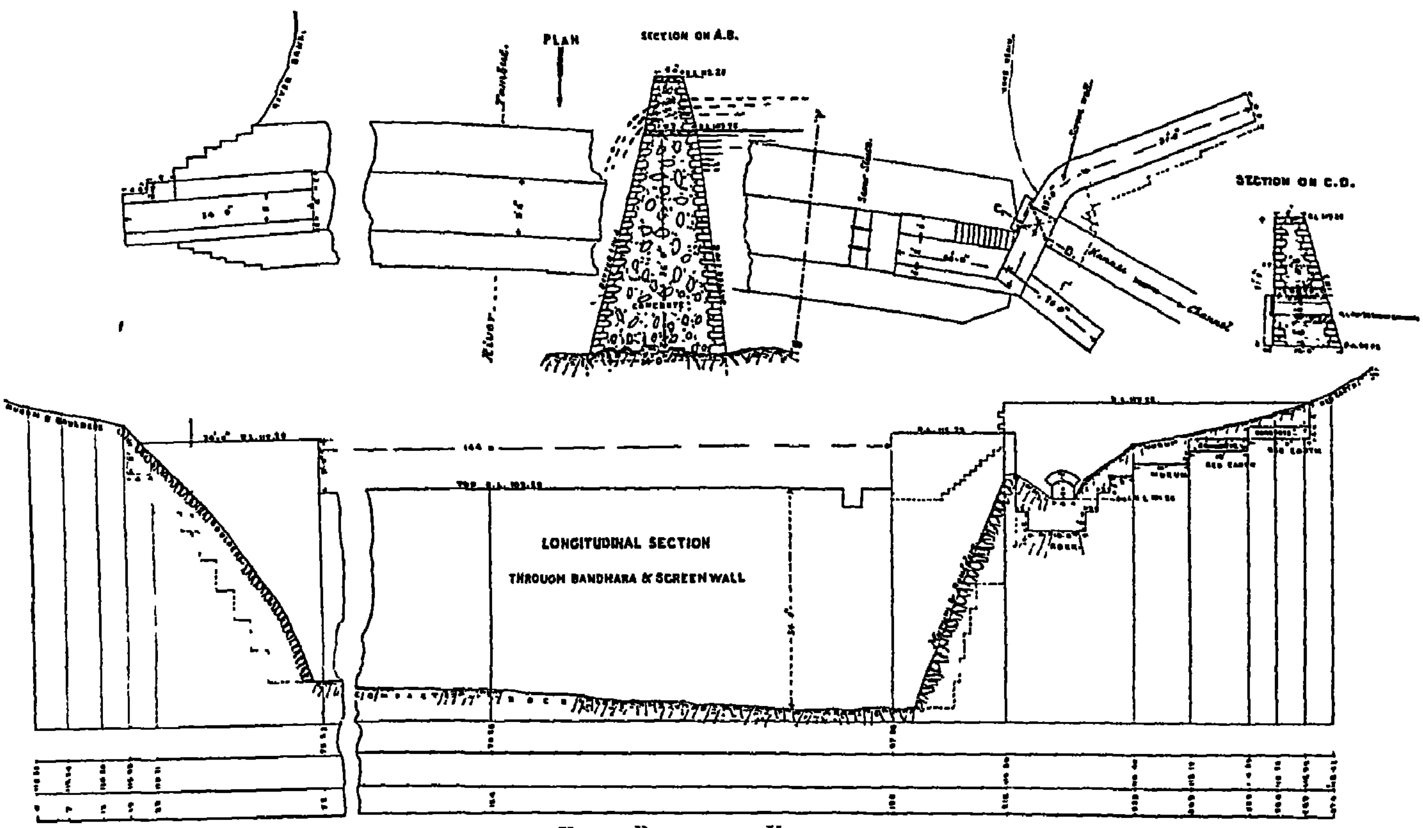
point. But the cutting action below the weir is not checked, and the bed of the stream is gradually cut away. The action may be slow, but still by small degrees the head on the weir is increased, and the toe of the talus of the weir is attacked. In such cases the only remedy is to continue to strengthen the weir as it may need it, by increasing the length of the rear slope, or by constructing subsidiary weirs below the main one to check the retrogression: this plan has been adopted on the Eastern Jumna Canal in the case of some of the torrents which cross it, and which are retained by dams across their beds.

CHAPTER VIII.

HEAD-WORKS IN ROCK AND BOULDERS.

Bandharas in Kandesh—Soonkesala Weir—Betwa Weir—Afflux of 6 or 8 feet on Betwa Weir—Under-sluices of the Betwa Weir—Head-sluice, Betwa Canal—Head-works, Mandalay Canal—Ravi Weir of the Bari Doab Canal—Training Works in the Ravi—Site of Head-works of the Bari Doab Canal not well selected—Under-sluices of the Ravi Weir—Under-sluice Gates of Ravi Weir—Head-sluice of Bari Doab Canal—Head-works of the Eastern and Western Jumna Canals—Under-sluices of the Jumna Weir—Head-sluice of the Western Jumna Canal—Jumna Weir—Regulation of Eastern Jumna Canal—Faizabad Dam—Khara Spur at Head of Eastern Jumna Canal—Ganges Canal Head-works—Temporary Dams at Head of Ganges Canal.

An interesting example of old native works, founded on rock, exists in the "Bandharas" of the Kandesh District[1] in Bombay. There are about 200 of these old works now in operation, and there are also many ruined and abandoned ones: they exist on almost every perennial stream



Kanasi Bandhara in Kandesh.

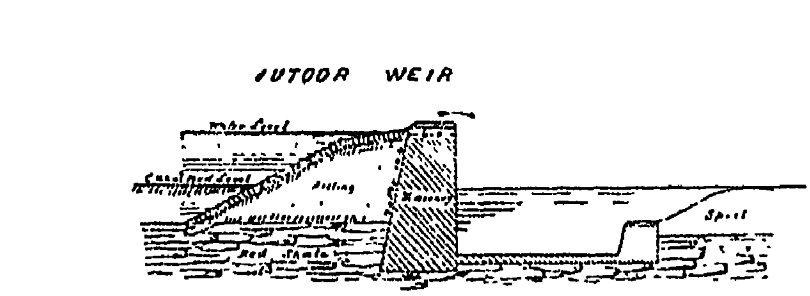
in Western Kandesh, and extend as far down the rivers as it is possible to construct them at any reasonable cost. These "Bandharas" consist of weirs, generally of solid masonry, but occasionally of earth or sand. Originally the weirs appear to have been wooden structures, or partly so, as there are curious square holes in the rock, near the sites of many of the existing works, which would seem to have been intended to receive wooden piles. The

[1] Note of Dec. 20th, 1904, by Mr. C. Shrinivasa-char.

sketch on the opposite page is a typical illustration of the style of construction of these old "Bandharas."

The channels which lead the water to the irrigated area or "thal" were aligned, originally, by the native constructors, with little regard to levels or cross drainages. As a rule physical obstacles were avoided by contouring the channel, and nullahs were crossed, on the level, by temporary bunds, which were, of course, carried away by every freshet in the nullah. However, with all these disadvantages, the "Bandharas" proved themselves useful, and many of them have been taken in hand and improved since the British Government assumed control of the country.

The way in which the irrigation is worked from these little perennial systems affords an interesting insight into the ancient village community system of Kandesh. The irrigated area, or "thal," is divided up into several plots, or "phads," and each irrigator has his share or field in each "phad." The different "phads" are sown wholesale in a regular rotation of crop. Thus, in the first year, one "phad" would be all sugar-cane, the next all rice, the third wheat, and so on. In the next year, according to rotation, the first "phad" would be laid down in wheat, the second in rice, and the third in sugar-cane. This arrangement is very convenient for the distribution of the water and is economical in many ways: thus, instead of each cultivator hedging his own field, the "phad" is enclosed as a whole; only one watchman is necessary, and the direction of the water from field to field in each "phad" is effected by one man.

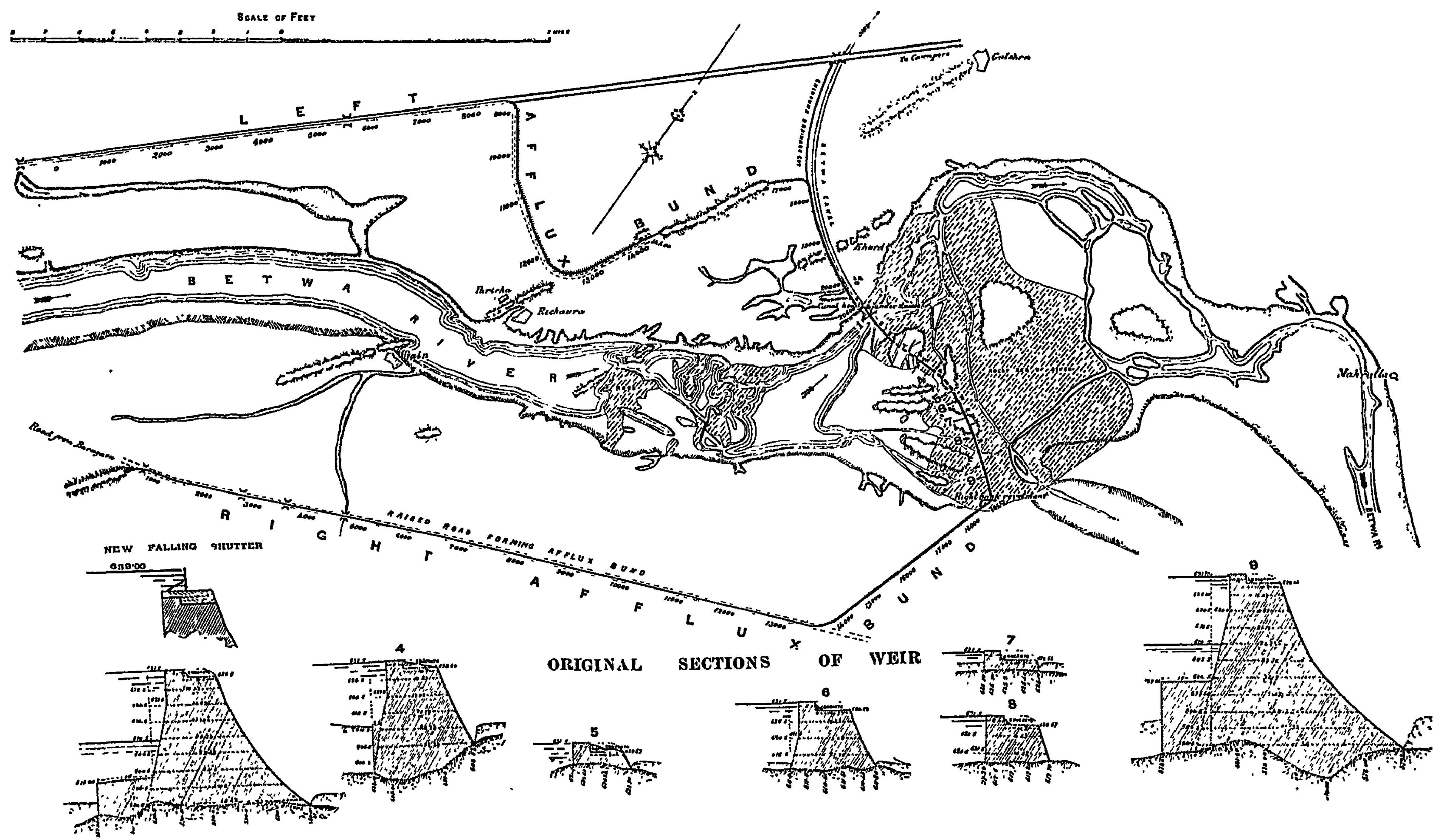


WEIRS ON THE KURNOOL CANAL IN MADRAS.

A rather remarkable example of a weir on a rocky bed is the one across the river Toombudra at Soonkesala in Kurnool. This weir forms the head-work of the Kurnool Canal, which was constructed by the Madras Irrigation and Canal Company [1] in 1866—70. It has a total length of 4,500 feet of clear overfall: the average height of it is 18 feet, but it varies from 6 feet to 26 feet in different parts of the river bed. The more lofty parts of the weir have the section as shown in the sketch on this page. The wall is of solid gneiss rubble masonry faced with limestone ashlar: the up-stream side of the wall has a batter of 1 in 4, the down-stream face being vertical. The lower parts of the weir have the same width of crest, but both faces of the weir wall are stepped to a batter of 1 in 8, and in these parts the wall is either of rubble masonry or of gravel concrete with gneiss rubble facing. The whole length of the weir is coped with limestone 12 inches thick, every alternate stone being 8 feet in length, and weighing about $1\frac{1}{2}$ tons. The rock of gneiss and trap, on which this weir is built, appeared perfectly sound and hard at the time the weir was erected. The sequel, however, has shown how necessary it is to exercise great care in bedding a weir with a vertical overfall. In this case the force of the scour was sufficient to dig out several deep holes in the rock, which had to be built up with masonry in cement.

The Jutoor weir on the same canal is built across the Kali river, which has a bed of soft

[1] "Proceedings of the Institution of Civil Engineers," vol. xxxiv.



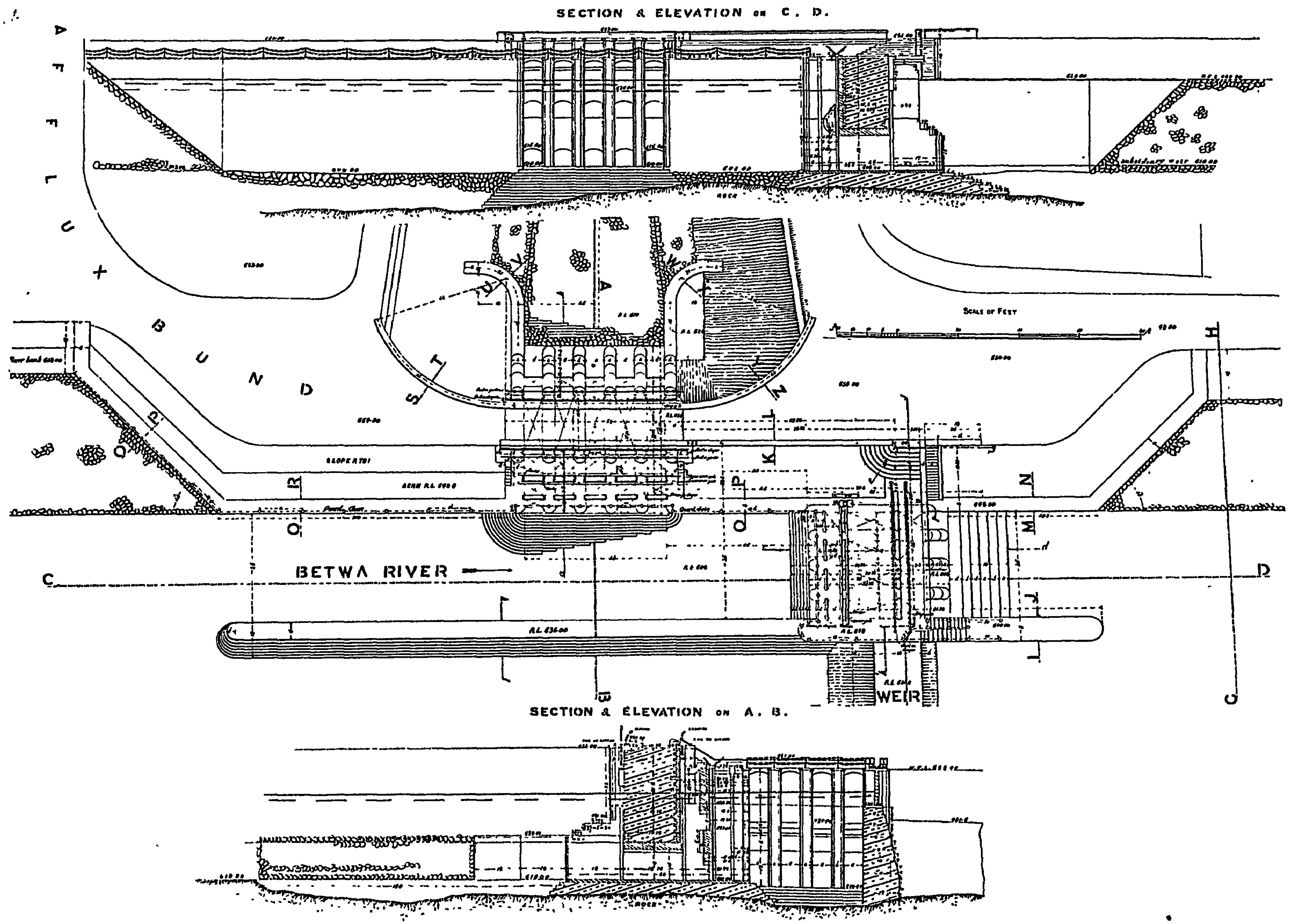
HEAD-WORKS OF THE BETWA CANAL.

shale. The weir is 6 feet broad on the crest, has a batter of 1 in 4 on the up-stream face, and is vertical on the down-stream side. Below the weir an ashlar floor of limestone is laid to protect the shale from the scour of the overfall. The floor, which is recessed below the river bed, ends in a dwarf wall, so that a water cushion is formed which aids in the protection of the floor. Experience has shown that in this case the length of the floor is insufficient. The weir is protected on the up-stream side by a bank of broken shale revetted with shingle.

The weir across the Betwa river in the United Provinces is a great contrast in design to those just described. It is founded on gneiss rock, and built of rubble masonry. The weir was designed to support the entire pressure from above in time of flood, on the supposition that the channel below was dry. The greatest height of the weir is 51 feet for a short length, and there is a considerable portion of it over 30 feet in height.

The head-works of the Betwa Canal are situated on the river Betwa, about 15 miles from Jhansi, in Bundelkund, in the United Provinces. The river has a course of about 360 miles from its source in Bhopal to the Jumna river, which it joins near Humeerpore. The catchment area of the river above the Betwa Canal is about 9,800 square miles, and the maximum flood discharge has been calculated to be 750,000[1] cubic feet a second.[2] This discharge is said to be due to the flow-off of as much as 80 per cent. of the rainfall. This is a large percentage, on so extensive an area, even on the rocky ground which forms the greater portion of the catchment. The slope of the river bed, immediately above the weir which has been constructed across the river, is only about 0·09 per thousand, or some 5 inches a mile, but the slope of the water surface in high flood averages 2·8 feet per mile, or 0·5 per thousand for a distance of 10 miles above the weir; and, immediately above it, the surface slope in floods is as much as 4·5 feet a mile. Before this weir was built, the bed of the river, in the dry season, was a series of long ponds, some as much as 3 miles in length, from which a mere trickle of water passed forward. Immediately below the weir the fall of the bed of the river is much more rapid: for the first 3 miles it is over 9 feet in the mile, so that the site of the weir is a very happy one. A large body of water can be impounded above the weir in the flat reach of the river. This storage above the weir is an essential part of the scheme of works, as the discharge in the river in May and June is little or nothing. The reduced level of the weir crest, as it was originally constructed, was 631·50, which made the height of the weir in the deepest part of the river bed more than 50 feet. But the crest has been raised to 633·00, and steel shutters 6 feet high and 12 feet broad have been erected on it. This has increased the storage capacity of the pool above the weir by 775 million cubic feet. The shutters are of the same type as those on the Sone weir (page 153), that is, they have up-stream diagonal tension bars hinged to the shutter and to the weir crest. The height at which these bars were hinged on the gates was such that the gates would fall, automatically, when the depth of water over the top was 2 feet, for one third of the gates, 3 feet for another third, and 4 feet for the remainder. Portable[3] sheers were, originally, provided for lifting the gates, but it was found that they could be more rapidly raised by hand. All the gates can be raised in an hour and a half. The tension bars of the gates have been injured occasionally by loose stones which have been washed over them, which shows that they would not be suitable in rivers with a boulder bed. It was found that the gates which were set to fall with 3 feet of water over them did not fall in series, as the others did, but fell singly or in couples: this was supposed to be due to difference in the frictional resistance of the heel of the gate on the weir crest; but it is not clear why this should

[1] But there is some doubt whether it does not exceed this figure.
[2] "Report of the Chief Engineer, Irrigation Works, N.-W. Provinces," dated Nov. 2nd, 1874, para. 38.
[3] Note by Mr. M. Nethersole, Superintending Engineer

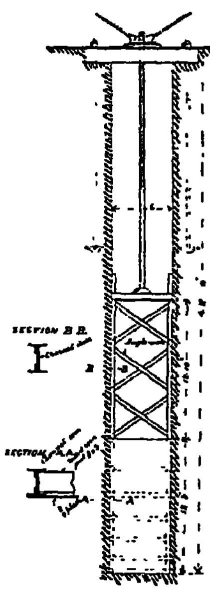


REGULATOR AND UNDER-SLUICES OF THE BETWA CANAL.

affect one class of gate more than another. Under standing orders the gates are lowered by hand when floods are imminent, and their automatic action has only been tested on two occasions. It seems doubtful whether this class of automatic gate is suitable to so great a depth of water as 6 feet: the liability to damage by shock is great. The bed of the river, at the site of the weir, and for a distance of half a mile or more below it, is good homogeneous gneiss rock. The weir is divided into two lengths by an island, on the eastern side of which the river bed is itself a natural weir, the rock in one place rising above the weir crest. The weir obstructs about 60 per cent. of the waterway below the original flood level of the river, and the result is an afflux which has been calculated to be from 6 to 8 feet. The flood level over the weir in a flood in 1901 was 649·4, or 16·4 feet above the crest of the raised sill, but the water below the weir stands at about 640·00, so the weir in such a flood is quite submerged. The flood of 1901 was not a maximum one: the flood of 1860 was 5 or 6 feet higher in reaches of the river beyond the influence of the weir. The afflux caused by the weir has necessitated the construction of an afflux embankment on each bank of the river, as shown in the Plate on page 116. These embankments have a width of crest of 20 feet, and are revetted with stone in parts. At a short distance below the main weir two subsidiary weirs have been constructed, one in each of the channels on either side of the island. These weirs have their crests at 610·00, which is 2 feet above the floor of the under-sluices, so that there is always a cushion of water below the main weir, the surface of which is 23 feet below the weir crest. These subsidiary weirs are of short length (300 feet or so), as the channels below the main weir are narrow.

It was anticipated, when the head-works of this canal were constructed, that there would be such heavy deposits of silt above the weir that it would be difficult to maintain a channel to the head-sluice of the canal. The velocity of the river in floods is about 7 or 8 feet a second only, which is not sufficient to move boulders or large shingle; but there is little material of this nature in the river, nor is there much coarse sand. The silt which is carried by the river seems to be generally of a fine nature, and it would be largely carried forward by the flood velocity, although a certain quantity would inevitably be deposited in the pool above the weir. In order, however, to give a great power of scour in front of the head-sluice, a longitudinal wall, or "divide" was constructed in the river bed for a length of 200 feet in front of the head-sluice and 36 feet from it, which confines the draught of the under-sluices to the channel in front of the canal head. (See plate on opposite page.) The under-sluices have four vents, each 6 by 12. The maximum discharge through the under-sluices would occur when the flood level above the weir was a foot or so above the weir crest, and before the level below the weir was appreciably raised by the discharge of the river: in that case a velocity of 25 to 30 feet a second would be obtained through the under-sluices themselves, and would be maintained for a few feet in front of the sluice, but would be gradually reduced as the full waterway of the channel, which is defined by the river wing and the face of the head-sluice wall, came into operation. At the head of this channel, which is 200 feet from the under-sluice, the waterway would be about 36 feet by 25 feet in depth, or 900 square feet, which is about three times that of the under-sluice vents, so that the velocity at the head of this channel would be from 8 to 10 feet a second. This is ample to remove all silt and sand, but is insufficient to move shingle the size of apples near the head of the river wing wall. The level of the floor of the canal head-sluice is 610·00, and the floor of the under-sluice is 608·00, which gives an additional advantage in excluding sand or other material which may be carried along the bed of the river. As the water below the weir is maintained at 610·00 by the subsidiary weir, the maximum head on the under-sluice is (631·50 —610·00) 21·5 feet when the reservoir is full. This head would be reduced in

flood time rather than increased, as the level of the water below the weir would rise more rapidly than the level above it. The under-sluice is fitted with two sets of draw-shutters working in grooves. The upper shutters are of iron and the lower ones of wood. The upper ones run in cast-iron grooves without friction rollers and are lifted by a screw 6 inches in diameter fitted with capstan bars in the nut-head, as shown in the sketch. The gates are very hard to move: it takes nine or ten men to move them under a head of 20 feet. The lower gates are drop-gates, they are of sâl wood 8 inches square, bound with heavy angle irons at the corners. They are intended partly as a safeguard in case of any accident to the iron gates, and partly as an aid in raising or lowering the upper gates when great heads have to be dealt with. The top of the drop-gates would never be far below water, but an arrangement has been fitted to them by which they can be fished from above and lifted by the travelling winch which runs above them on the crest of the under-sluices. When the drop-gates are lifted they are suspended on to let-go gear which can be easily released with a blow when it is desired to drop them: these gates, however, have not been much used: it is difficult to get them down, owing to the great velocity of the stream below.

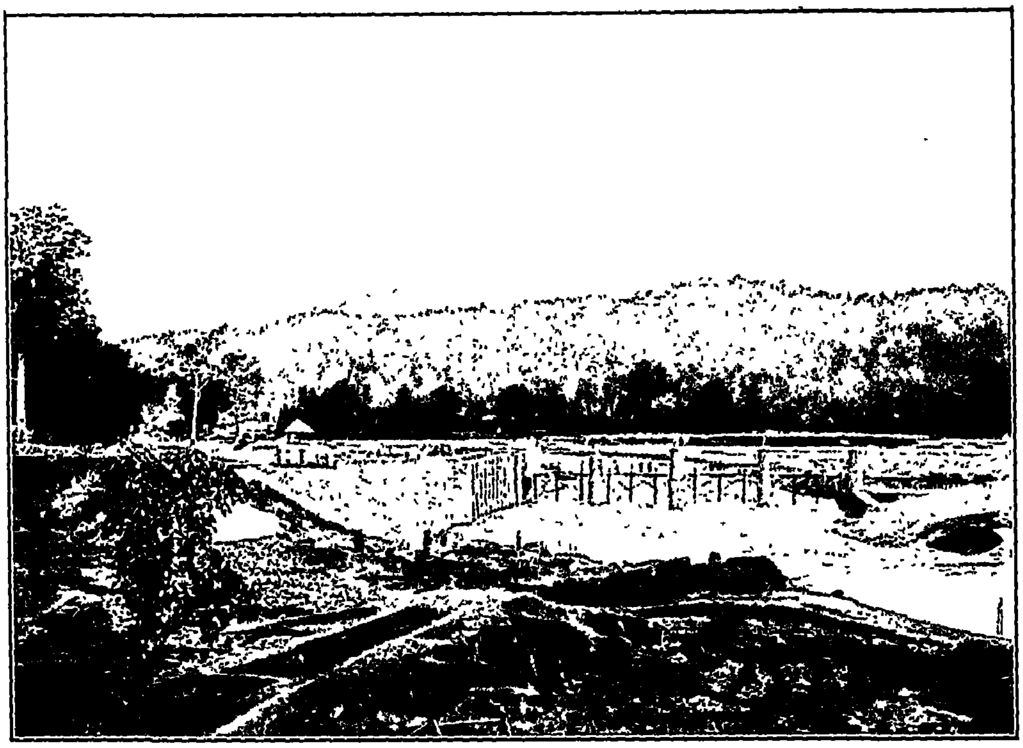


UNDER-SLUICE GATES, BETWA CANAL.

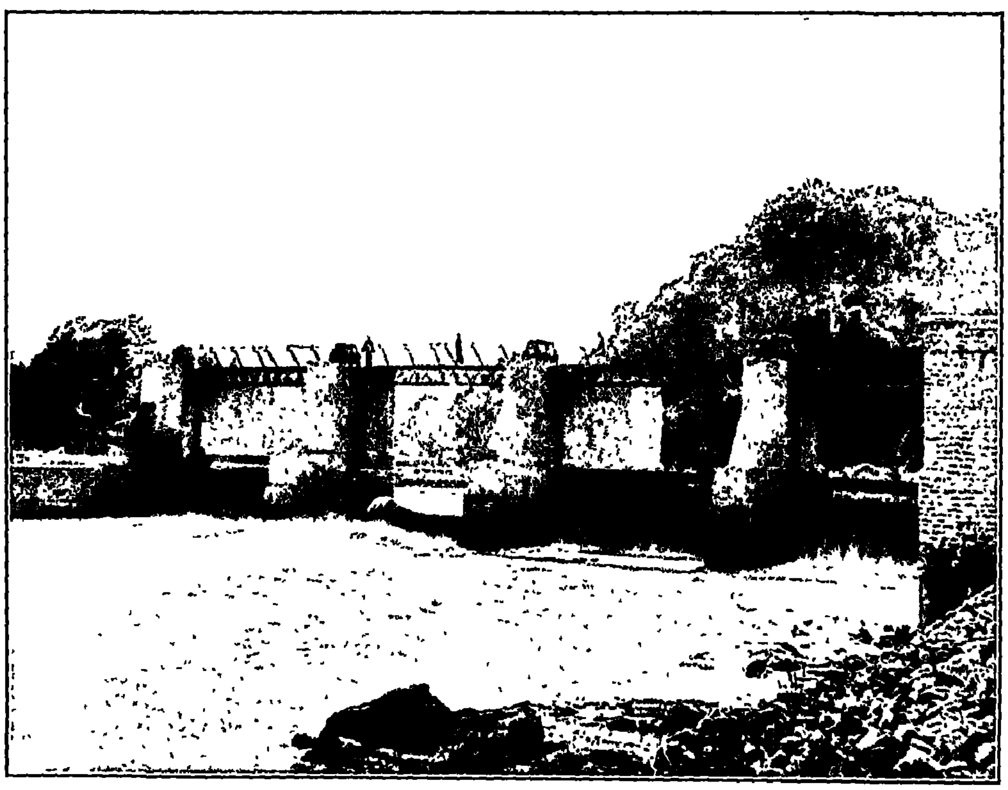
The head-sluice is founded, like the weir and under-sluice, on rock. The floor of it is 610·00 and the water level of the canal is 623·00, so the maximum head is 25 feet with a flood at 648·00. The water can be drawn into the canal through two lines of vents. The upper line is used when the water in the reservoir is high: the lower line when the level has fallen so far that the discharge from the upper line is insufficient. This draught from the surface reduces the silt carried into the canal. The vents are fitted with iron draw-gates: each gate covers an opening 6 feet by 6 feet. The gates are lifted by screws with capstan nuts: the screws of the upper and lower line of gates are only separated by a few inches, so that the upper gates must be depressed on to their seats before the lower gates can be lifted: the capstan heads are moved from the nuts of the upper to the lower gates when a change is necessary. In addition to the draw-gates in the head-sluice, there are two independent lines of drop-gates (as shown in the Plate on page 118)—one set is above the vent which runs through the sluice, and the other is below it: they cover openings 10 feet high by 6 feet broad, and are of timber, similar to the drop-shutters of the under-sluices. The upper line of drop-gates runs in cast-iron grooves, but the lower ones in stone grooves only. A travelling winch runs on rails above for lifting the drop-gates: this is far less powerful than the one on the under-sluice. Both in the case of these gates and in those of the under-sluices an arrangement has been made so that they can be jumped down on to the floor if they fail—as they do in a strong current—to reach the floor by their own impetus when they are released from the let-go gear which holds them above. On the top of each gate two short timber ends can be fitted into sockets formed by the angle irons with which the gate is bound: there is a spare gate, similar in every way to those in place, which can be placed by the traveller in the groove above the one which it is required to jump down. This upper gate is lifted by the traveller, put on the let-go gear, and then released. It acts as the monkey of a pile-driver in forcing the lower gate down, falling each time on the timber ends of the lower gate.

The weir across the rocky bed of the Nira river at Vir in the Bombay Presidency has some features in common with the weir on the Betwa. A description of this work has been given in Chapter V.

The head-works of the Mandalay Canal are at Sedaw, on the Madaya river, some 32 miles



Head Regulator and Under-sluices of the Mandalay Canal.

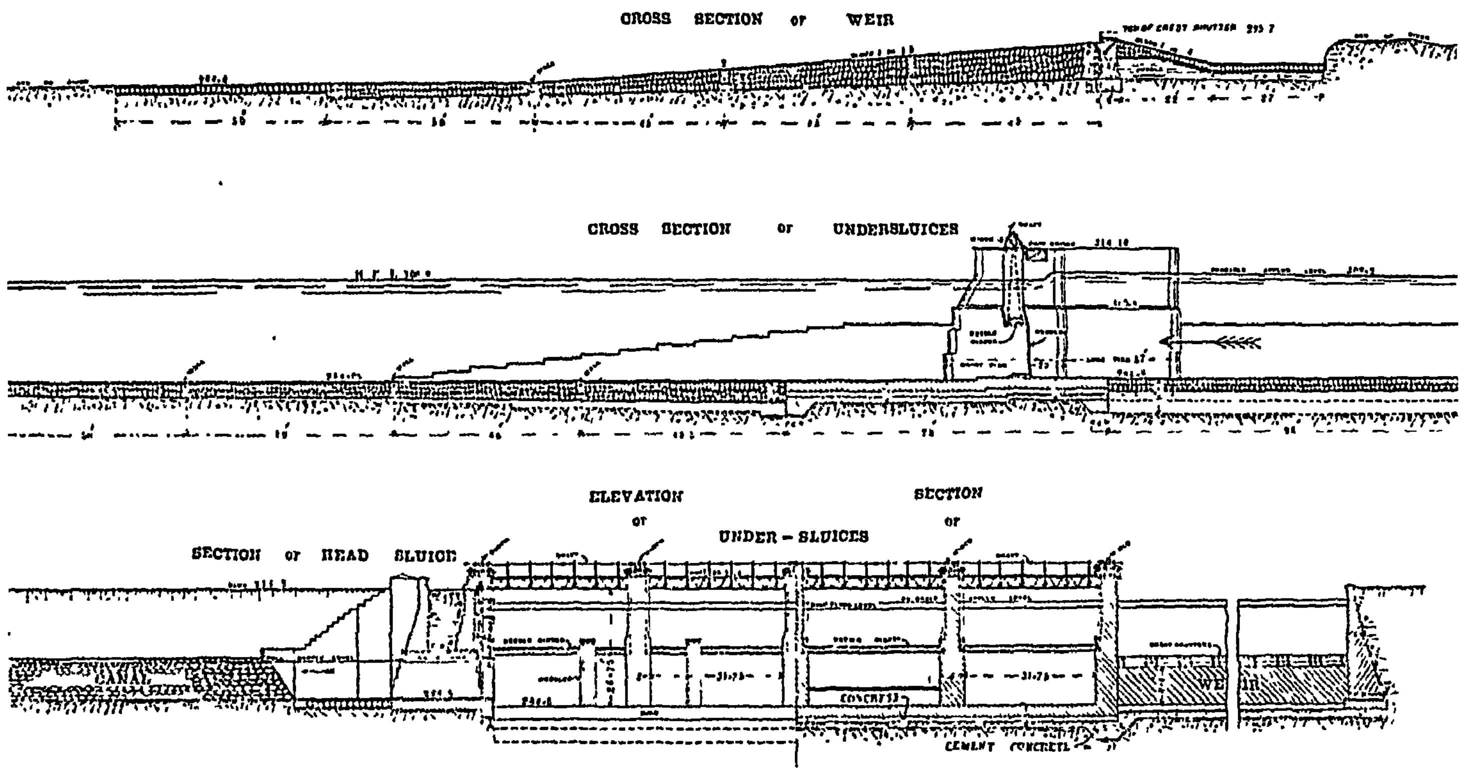


Under-sluices of the Madaya Weir on the Mandalay Canal.

[To face page 120.

north of Mandalay. They have features of interest. The Madaya river has a catchment of 1,322 square miles; a bed slope of $2\frac{1}{2}$ to 3 feet in a mile; a cold-weather discharge of 400 to 600 and a flood discharge of about 70,000 cubic feet a second. The maximum velocity is 9 feet a second in floods. The site of the head-works is that of an old weir which was constructed by the Burmese to lead the water of the river into Mandalay. There is an outcrop of rock on the left bank of the river, but it does not extend across it, and is not uniform in quality. The head regulator and half the under-sluices are founded on rock; the other half of the under-sluices and the whole of the weir are founded on shingle and gravel.

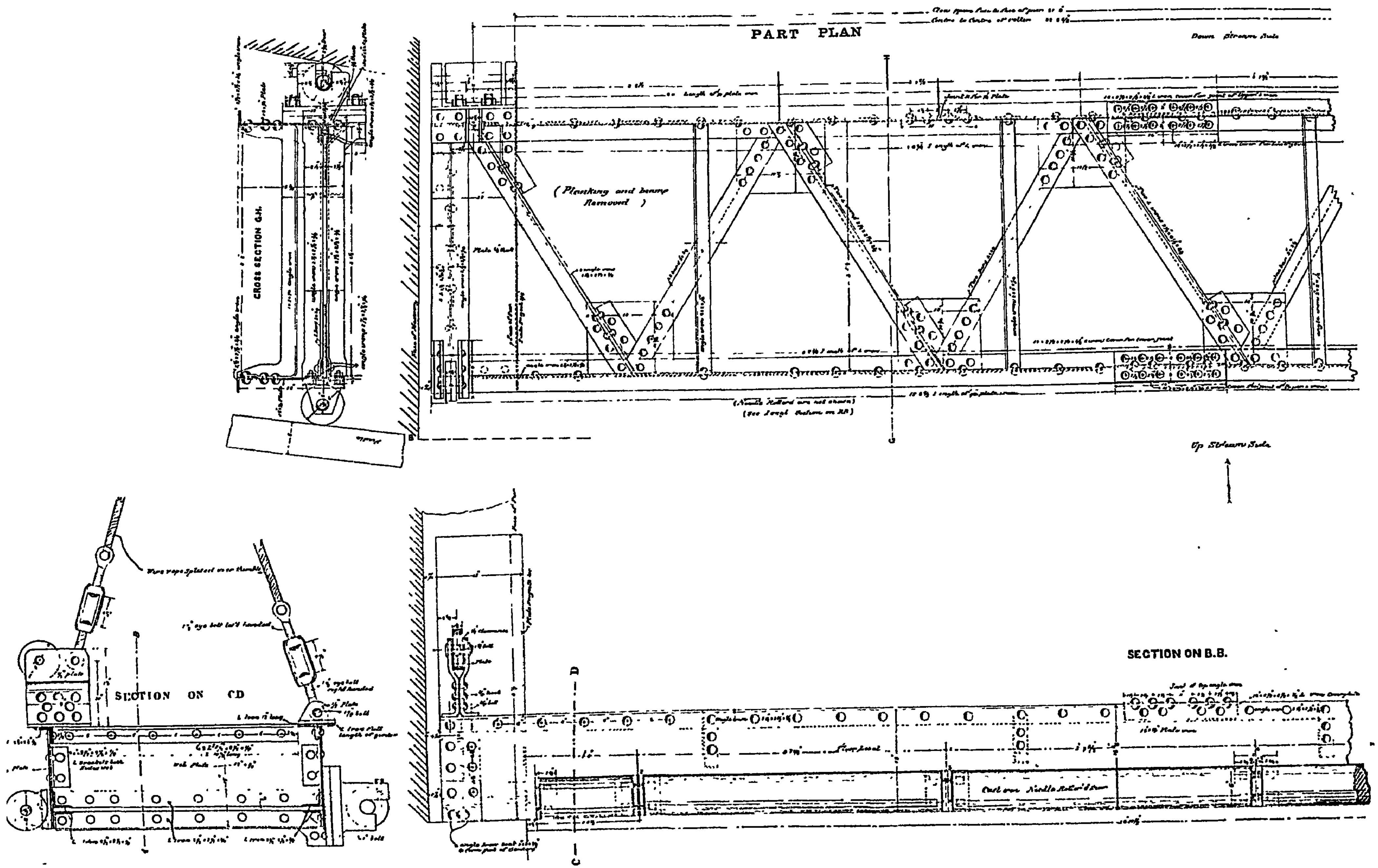
The weir is only 250 feet long; the crest is 4 feet wide and 8·4 feet above the floor of the under-sluices. Crest shutters 3 feet high stand on the crest; each shutter is 8 feet long and



Sections of Mandalay Weir and Under-sluices

3 inches thick, of teak wood. They are held erect by tension rods, and are similar in principle to those of the Sone weir illustrated on page 153.

The under-sluices were originally partially completed with tenvents 10 feet in width only. It was intended to fit these vents with shutters 12 feet in height, which would fall automatically when topped by a flood; but it was found necessary, before the works were completed, to modify this design materially. In May, 1899, during an exceptional flood, the water rose 20·7 feet above the floor of the under-sluices. The flood carried, as floods often do in the Madaya river, huge masses of logs, brushwood, bamboos and uprooted trees. Some of these trees exceeded 60 feet in length. The trees and driftwood, &c., caught in the piers of the incomplete under-sluices and blocked them. The design was revised; the first piers were dismantled and the vents were increased from 10 feet to $31\frac{3}{4}$ feet in width. But even with these large openings the logs do accumulate: on July 4th, 1902, a huge mass of trees, logs, and brushwood became blocked in the sluices. The timber had to be sawn up and passed through the sluices piecemeal. A boom of logs, fastened diagonally to the current, is now being tried; it is hoped that it may lead the trees to approach the sluices end on and so pass through without jamming. There are four bays in the under-sluices formed by piers which are 29·36 feet in height, 6 feet



NEEDLE GIRDER ON THE MADAYA WEIR, MANDALAY CANAL.

thick for the lower 15½ feet and 4 feet thick above. Part of the foundations are on rock. Where shingle is met with the foundations consist of 2½ feet of concrete, of which 12 or 18 inches at the base is laid in cement; above the concrete there is 6 inches of coursed rubble masonry, and then the entire floor is packed with 2-feet stone blocks on end, with the interstices filled with rammed cement concrete. Above and below the sluices the bed of the river, except where there is rock, is pitched with stone. A section of the weir and under-sluices is given on page 121.

The under-sluices are fitted with a needle dam, which can be opened in a few minutes by lifting the steel girders which hold the heads of the needles. The needle[1] girders are 33 feet 8⅝ inches in length, 3 feet 3 inches in width, and 1 foot 3 inches in height: details of their construction are given in the Plate on page 122.

To receive the ends of the girders recesses have been left in the sides of the piers, and, when fully lowered, the bottoms of the girders rest on ledges 12 feet above the floor of the under-sluices. Both the up and down stream ends of the recesses in the piers are lined with iron plates; the rollers at the ends of the girders travel on these plates when the girders are being raised: along the lower up-stream face of the girder, cast-iron rollers, 6 inches in diameter, are fitted. These rollers support the upper ends of the needles when the under-sluices are closed. Each needle girder is raised by four flexible steel wire ropes 2½ inches in circumference, which are attached to the four brackets on the top of the girder and to the drums on the winches above it. There are five sets of double-purchase winches for raising the girders. The shafts between the winches are supported by angle iron struts fixed to the down-stream girders of the overhead bridge. The needles are of teak wood 15 feet by 5 inches by 3 inches. The heads of the needles are sloped off on the up-stream side and perforated with slots, which are all in a horizontal line when the under-sluices are closed. The needles in each bay are threaded together by a wire rope passing through the slots, which is long enough to pass under the needle girder and behind the piers to the down-stream wing wall of the under-sluices, where it is attached to a bolt securely built into the masonry at a high level. The needles in any vent, when released by the raising of the girder, all fall simultaneously, and are brought up by the anchor rope about 100 feet below the under-sluices. They are then unthreaded, carried up, and restacked on the head-works. The needle girders when they have been raised, are suspended by hooks and chains, which are hung from the overhead bridge.

This system of a needle weir in under-sluices has the merit of cheapness and simplicity. It is doubtful if it has any other. It is slow, laborious, and, under some conditions, not efficient. It takes, for instance, about twenty minutes to raise, and fifteen minutes to lower, each of the needle girders in the Madaya weir. The closing of each bay, of 31¾ feet, takes one and a half to two hours, and as each bay is closed and the water is headed up, the closing becomes more and more difficult. Needles are usually broken in the operation; it often occurs that several attempts are made before a needle can be secured in position.

The head regulator has twelve vents 5½ feet broad and 8¼ feet high, with 3-feet piers between them. Each vent is provided with three shutters, 2½ feet, 3 feet, and 3½ feet in height respectively, raised by screw gearing and capstans from the roadway above the regulator. The design, in this respect, is similar to that of the Bezwada head-sluice, which is illustrated on page 181. The floor of the head regulator is 2½ feet thick, and its surface is 1·7 feet above the floor of the under-sluices. A section of the regulator is given in the Plate on page 121.

The weir across the Ravi river at the head of the Bari Doab Canal in the Punjab is an example of a weir of the second class in the boulder formation. The weir itself is simple, and

[1] Note by Mr. Nyall, dated Aug. 17th, 1904.

is only 3 feet above the original river bed; in parts where the river bed was deep the weir wall was carried down to it. High floods rise to about 10 feet over the weir crest. The wall itself is in boulder masonry, and it shows what good results can be obtained with small stones, provided they are thoroughly well set in good mortar. This wall is built with comparatively small boulders, hammer-dressed on the surface, thoroughly well bedded in mortar, and although there have been several accidents to the weir this wall has stood well. The velocity over the weir in flood is said to be 15 or 20 feet a second, and the mortar joints are much scoured out by the water and sand, but the stones are rarely displaced. The slope of the river bed above the weir is over 20 feet in the mile, and boulders the size of a man's head are carried down it.

There has been considerable difficulty in this case in keeping open a channel in front of the head-sluice: heavy training works have been required in the river bed above the weir to direct the cold-weather channel towards the left bank. The movement of shingle in the river is considerable, and the weir itself is now completely buried in parts by shingle and boulders. The training works consist of a series of embankments and spurs, which were at first constructed as bunds faced with boulder pitching; but this did not stand, and considerable portions of some of these spurs are now in masonry. The result has been successful, as there is now a good channel leading to the under-sluices, and, in the dry season, the entire discharge of the river is passed into the canal.

In this case the selection of the site for the head-works of a canal from the Ravi river was not a happy one. The site was higher up the river than was necessary in order to utilise the available water supply. The great velocity in the river and the flow of shingle and boulders has caused great trouble and expense, and the cost of the construction of the canal itself has been high owing to the very rapid fall in the country. The canal takes out from the river in 53 feet of cutting, and it is a very pretty piece of work: the soil is full of boulders and the deep slopes at the canal head are neatly revetted, in steps, with them. The slope of the bed of the canal in the first 12 miles varies from 1 in 1,250 to 1 in 1,500, according to the depth of shingle deposits in the canal, and the depth of water from $4\frac{1}{2}$ to $5\frac{1}{2}$ feet; the bed width is 112 feet: the maximum discharge was designed to be 3,700 cubic feet a second, but 4,600 cubic feet are now passed, and 1,900 cubic feet in the Salampore feeder, or 6,500 cubic feet per second in all. The velocity rises to as much as 5·7 feet a second. Although the canal has this steep slope, the bed of it comes to the surface within 3 miles, and a little irrigation is effected in the fourth mile. But the slope of the country is so rapid that in the first 12 miles of the canal the bed level drops more than 200 feet, of which 150 feet is obtained by 19 rapids or weirs constructed in the canal and the rest by the slope of the canal bed. The cost of the construction and maintenance of these works has been great, and little or nothing has been gained by tapping the river at so high a level, and then dropping the water by fall after fall and rapid after rapid down to the point where the slope of the country is more suitable—nothing, at least, except beauty: the first 12 miles of the Bari Doab Canal is perhaps the prettiest piece of canal scenery in the world. The channel winds about through beautifully wooded banks in a shallow stream paved almost with boulders; round nearly every curve a new rapid of foaming water comes in view, and the stream, flowing with the great velocity it has, is bright and gay. The whole of the channel sides from the second to the seventh mile are revetted with boulders to protect the banks from erosion, and altogether nearly 19 miles of the canal slopes have been pitched with boulders, laid dry, by hand. A varying length is still added every year as occasion demands. At every few yards there are signs of the care and skill which has proved to be necessary to deal with such high velocities. Some 10 or 15 miles lower down the Ravi

river, the slope of its bed is much less, and, although the width is greater, the head-works at that site would probably have cost less money: it would have been possible to have commanded an equal area of land, and very nearly the same land, with less original cost and less expenditure in maintenance.

The under-sluices in the Ravi weir have been the result of experience: they now consist of twelve openings of 20 feet each. They were originally constructed with smaller openings and low piers with grooves, which it was intended to operate with *kurries*, as they are called in the Punjab, that is, single baulks of timber, dropped horizontally into the grooves. The piers were not successful; they were knocked over and the under-sluices were reconstructed. The heavy action on the floor, which has necessitated frequent and heavy repairs, is increased by the training works above the weir which throw the full force of the stream towards the canal head, and tend to diminish the portion of the flood passed over the weir itself, and to increase the portion which passes through the under-sluices. The weir, as has already been stated, is partly buried by shingle, and the bed of the river is generally filled up to the crest level. It is not improbable that the increased strength which has been required is due to some extent to a retrogression in levels (page 112) of the bed of the river below the weir. The under-sluices are very strongly built, the floor, which is of hammer-dressed boulders, is remarkably good and stands the enormous velocity in a wonderful way; the stones are rarely more than 14 inches or 16 inches square, but they are very hard and thoroughly well set in mortar: this floor has stood much better than some others which were constructed of large ashlar blocks. Owing to the flow of boulders through these under-sluices it was found necessary to face the lower portion of the noses of the piers with baulks of wood and the upper parts with sheet iron. It is said that the flow of the shingle and boulders over the floor can be distinctly heard in a flood.

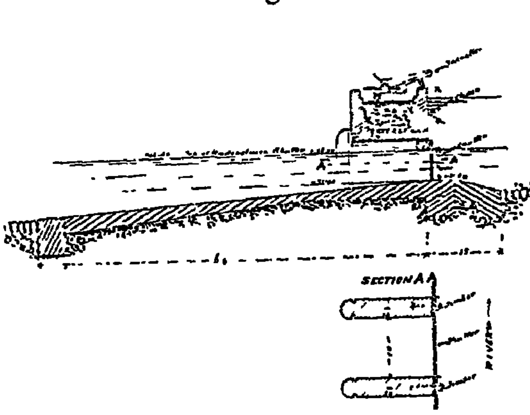
The under-sluice gates are in two rows, in separate grooves, parallel to each other. The lower row of gates is 3 feet and the upper 4 feet high. It was found very difficult to get the lower small gate down when it was dropped, as it was light, and the velocity of the stream is greater than in the Sirhind Canal under-sluices, where the heavier gates drop without any difficulty. The old 3-feet gates are being replaced by 4-feet ones, which go down much more readily and are easily rammed tight. The old gates were lifted by fixed gearing in the piers above, but this was very slow. A tramway over the whole length of the under-sluices, carrying two travelling winches, is now nearly completed. These winches will, it is calculated, be able to lift all the gates in the under-sluices in one and a half hours. The flood begins to arrive one hour after warning of its approach has been received from an electric automatic alarm bell operated 16 miles up-stream. Some gates are always open in the flood season, and if the travelling winches can clear the entire under-sluice in one and a half hours, it is sufficiently rapid for safety. The fixed gearing used to take much longer. In order to obtain the large increase in discharge, which has been passed into the canal, it was necessary to raise the level of the pool above the weir by 2 feet. This has been done by raising the floor of the under-sluices by one foot, and by increasing the height of the lower gate from 3 feet to 4 feet. It is interesting to notice that in many cases in India the same necessity for raising the level of the pool has arisen. In some cases the object has been to obtain a larger discharge for irrigation, and in others to enable a steeper gradient to be obtained which would induce a scouring velocity in the canal. It would be a good rule in future always to construct a weir and its sluices so that if necessity arose the height of it could be easily increased.

The piers of the under-sluices have to resist many heavy blows from logs of timber which are sent down the river in the floods. The piers are alternately long and short, so that the nose of one is above the nose of the next. As the logs float down the long pier strikes any log

which might get across the two piers and gives it a twist which sends it shooting through the vent.

The head regulator, or head-sluice, on the river face has twenty-three openings of 10 feet each. The floor is 113·11, and the top of the permanent stand gates is 1,133·00, which is 2½ feet above the new raised sill of the under-sluices. The peculiarity of this sluice is that there are no noses to the piers on the river side, and that there is only one groove, on the up-stream side, to guide the shutters. This groove is formed of timber, as shown in the sketch below: it is believed that this arrangement was dictated by the damage done by the flow of logs and boulders in floods.

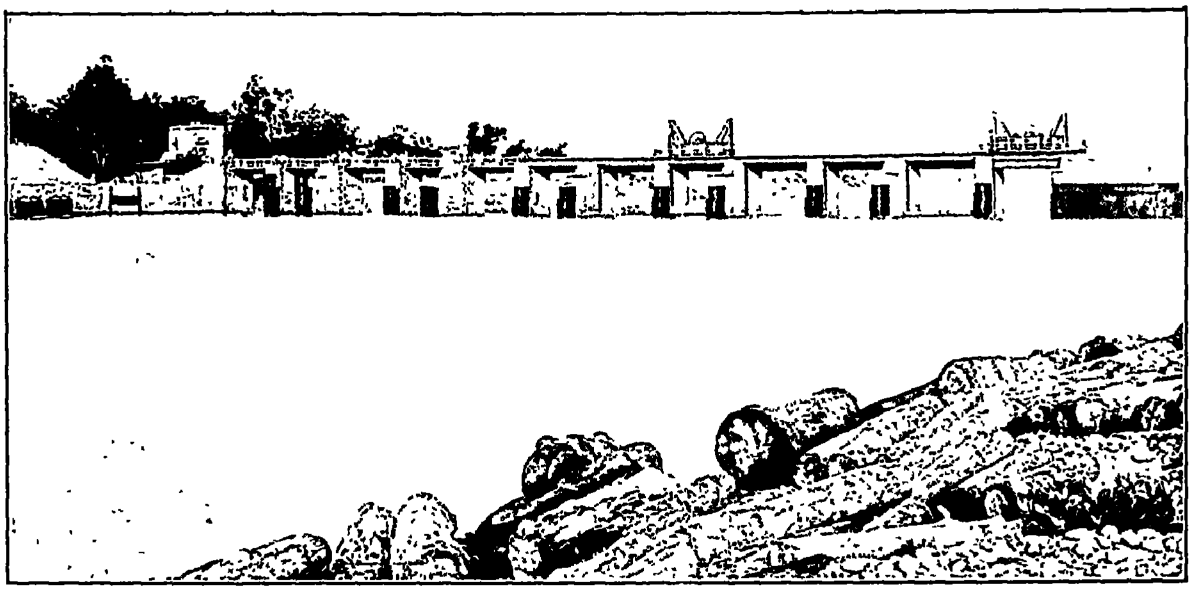
The floods in the Ravi are sudden, violent, and generally of short duration: the fall of the river is great and the rainfall on the hills above is quickly discharged. In order that no excessive strain may be thrown on the under-sluice floor it is necessary to watch the river, during the months of July to October inclusive, very closely, and to work the under-sluice gates frequently. If the gates are not opened when the water begins to rise, the flood will make until there is a dangerous overfall over the shutters, and it may become very difficult, if not impossible, to lift the lower gates. On the other hand if the gates are kept open too long, perhaps in anticipation of a flood, the supply in the canal, which, at this time of the year, requires to be well sustained in order to supply the *kharecf* (wet season) crops, falls too low. Very strict rules are enforced during these months: double sets of men are employed on the under-sluices. An automatic gauge is fixed on a rocky cliff 20 miles up the river. When floods rise to a certain point connection is made with an electric sounder at the under-sluices. All hands then turn out to be ready for the flood, which takes about two hours to travel the 20 miles. There is also a telephone between the two places.



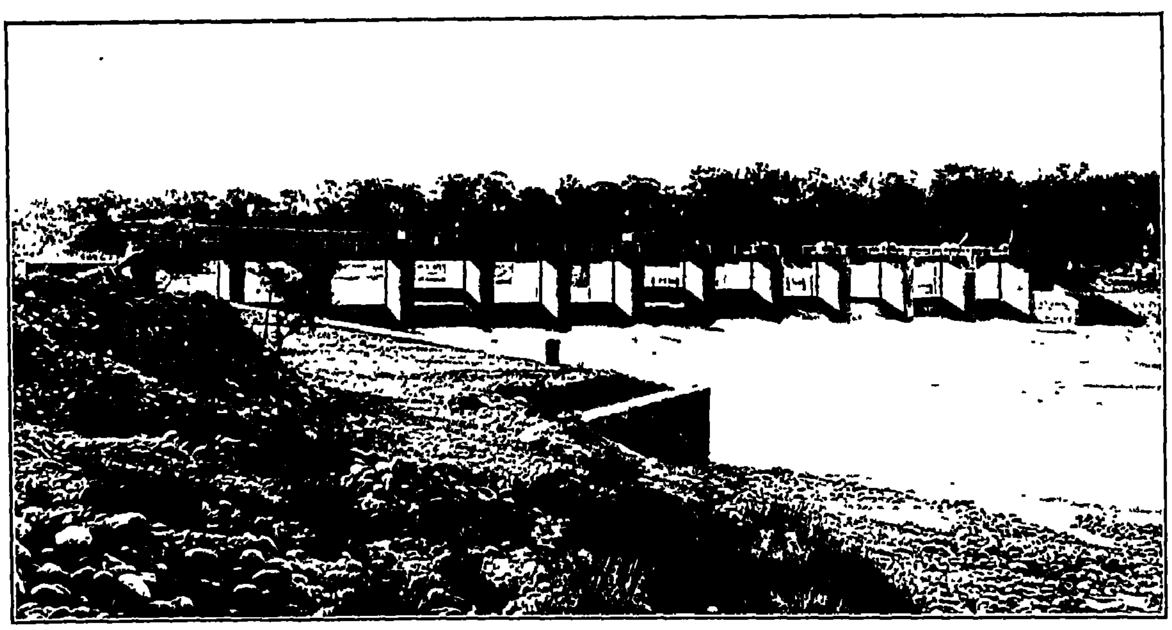
SECTION OF HEAD-SLUICE, BARI DOAB CANAL.

The head-works of the two canals, called the Eastern and the Western Jumna Canals, which take off the Jumna near the point where that river debouches from the Sewalik range of hills, are in the boulder formation. Both these canals were originally supplied by temporary dams or spurs which were annually constructed in the boulder-bed of the Jumna, and one of them is still supplied in that manner. The two canals are under different administrations: the Eastern Jumna is in the United Provinces, and the Western Jumna in the Punjab. At times the entire discharge of the river is taken into the two canals, and the equitable division of the total available supply used, occasionally, to be a source of difficulty between the Governments of the two provinces. It was partly to avoid these difficulties, but mainly in order to supply the canals with less annual labour and risk, that a set of permanent head-works was constructed across the river. These works now form the source of supply of the Western Jumna Canals, but they have never been used with reference to the Eastern System, which is still supplied in the old manner, which will be presently described.

The permanent head-works are shown in the Plate on page 127, and a reference to the Plate on page 130 (which shows the head of the Eastern Jumna Canal) will make the general arrangement more clear. Advantage has been taken of an island in the river at the site of the permanent head-works, which was largely increased in size by the excavation of the channel below the under-sluices; on each side the banks of the island are heavily revetted by boulder

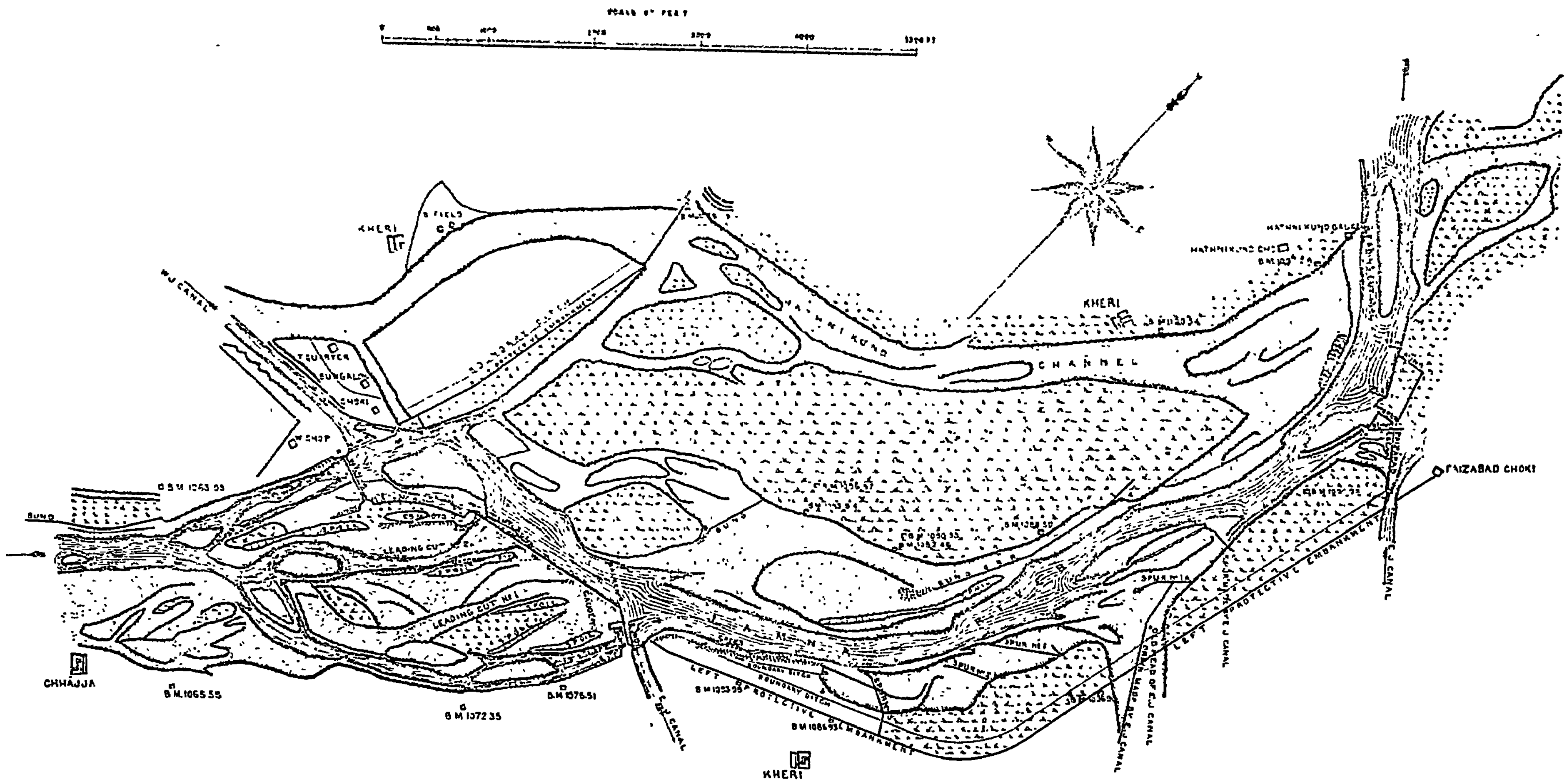


UNDER-SLUICES, MADHOPUR WEIR, BARI DOAB CANAL, UP-STREAM.



UNDER-SLUICES, MADHOPUR WEIR, BARI DOAB CANAL, DOWN-STREAM.

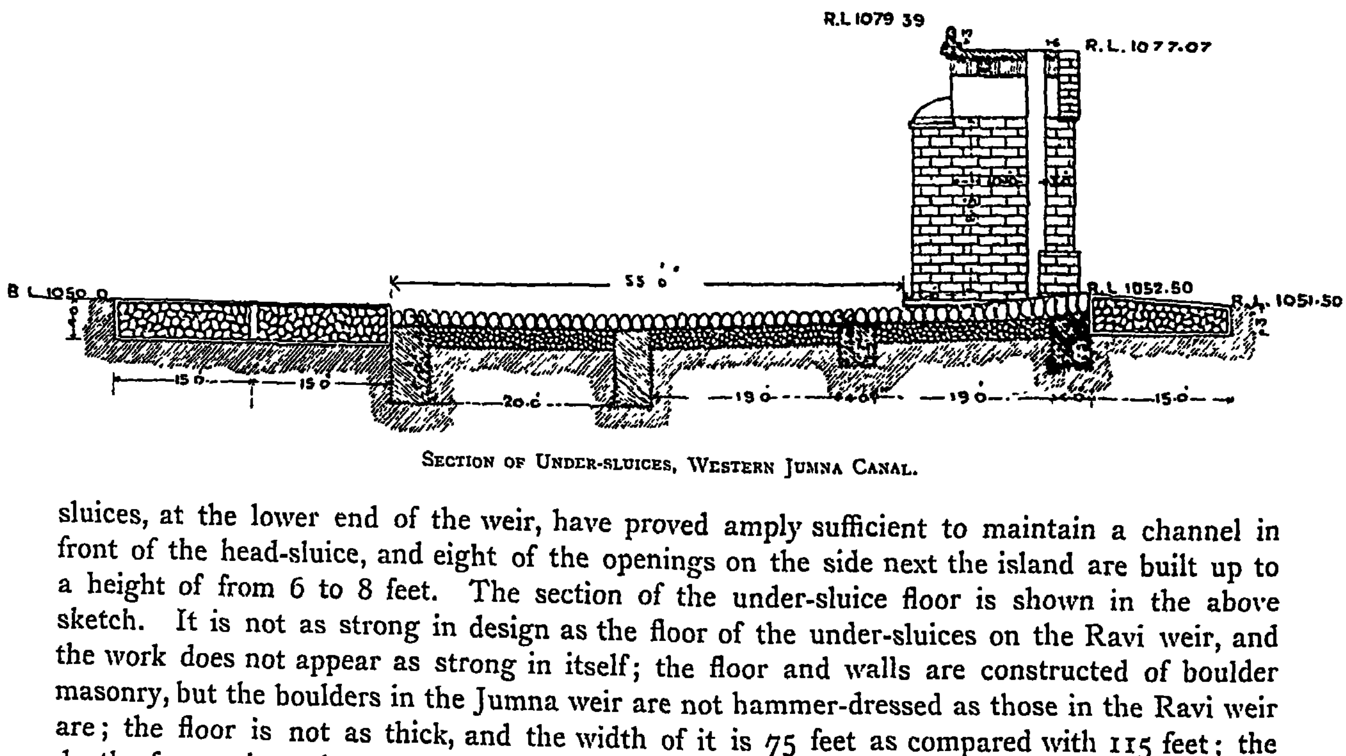
[*To face page* 126.



PERMANENT HEAD-WORKS, EASTERN AND WESTERN JUMNA CANALS.

pitching, with a masonry toe to the slope, and the nose of it is protected by a strong revetment wall of boulder masonry from which the weir takes off. The weir is built diagonally across the river, and the crest of it is not horizontal, but is sloped from the upper to the lower end: the level of the crest at the east end is 1069·00 and at the west end 1063·75. The fall of the river bed is 16 or 17 feet in the mile. The eastern under-sluice, which was intended to have been worked to keep a channel open in front of the Eastern Jumna Canal head-sluice, which is immediately above it, has seven openings of 21 feet, the floor level being 1061·00 and high flood about 1078·50. These under-sluices are completely blocked with shingle, which has accumulated up to the level of the weir crest and in front of the head-sluice. The under-sluices appear insufficient to maintain a channel in front of the sluice, but they are not regularly worked, as the head of the Eastern Jumna Canal is not used; a channel 50 feet broad was excavated one year through the shingle to these under-sluices, but it filled up again in the floods.

The western under-sluices consist of ten openings of 20 feet and eight openings of 23·16 feet; the floor level is 1052·5 and the depth of water in flood about 17 feet over the floor; these

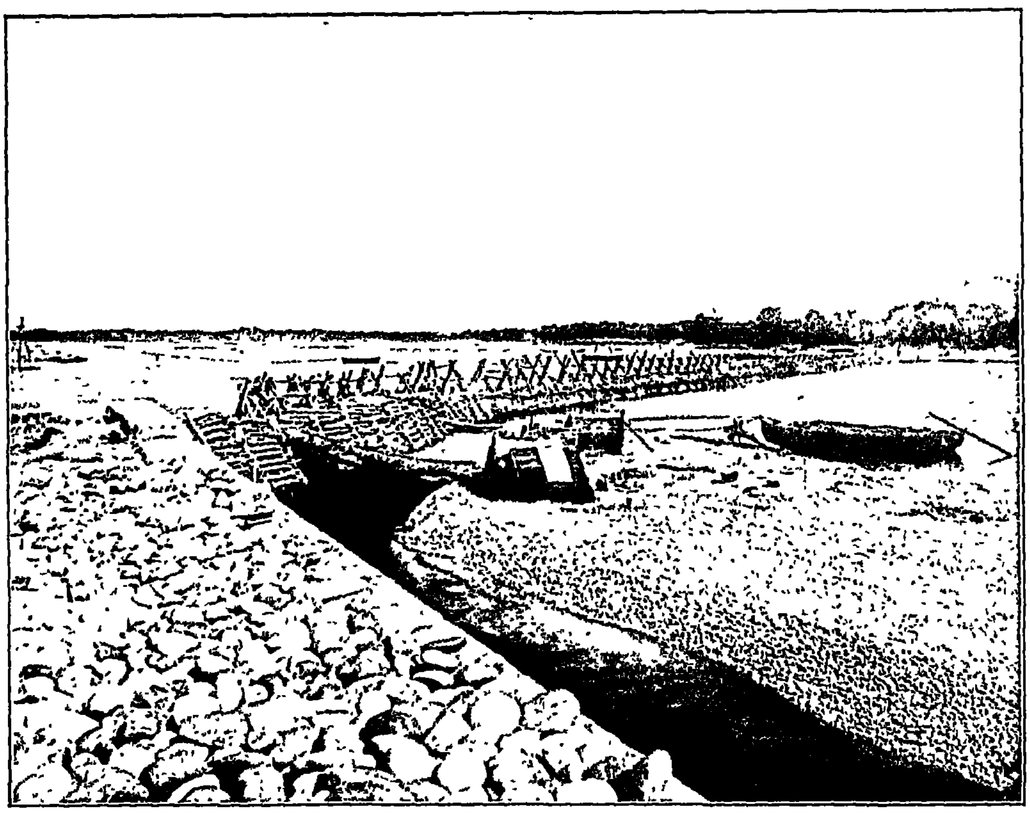


SECTION OF UNDER-SLUICES, WESTERN JUMNA CANAL.

sluices, at the lower end of the weir, have proved amply sufficient to maintain a channel in front of the head-sluice, and eight of the openings on the side next the island are built up to a height of from 6 to 8 feet. The section of the under-sluice floor is shown in the above sketch. It is not as strong in design as the floor of the under-sluices on the Ravi weir, and the work does not appear as strong in itself; the floor and walls are constructed of boulder masonry, but the boulders in the Jumna weir are not hammer-dressed as those in the Ravi weir are; the floor is not as thick, and the width of it is 75 feet as compared with 115 feet; the depth of water in each case is much the same, but the flood discharge of the Jumna is believed to be larger than that of the Ravi. These under-sluices on the Jumna show no sign of pooling below the floor—indeed, the shingle has accumulated below them.

The under-sluice shutters are of iron similar to those on the Chenab weir (page 191); there are two shutters in every vent, each spanning the opening of 20 feet; each shutter is 4 feet 3 inches in height and runs in a separate pair of vertical cast-iron grooves built into the piers; the upper shutter overlaps the lower one when it is down by 6 inches, so that the crest of the two shutters is 8 feet above the floor. There is a chain permanently attached to each shutter, so that it is not necessary to fish for the eyebolt when they have to be raised. The shutters are lifted by a traveller running on rails on the piers. There is sometimes a difficulty in getting them down; they are bumped down with a long pole or *bullah*.

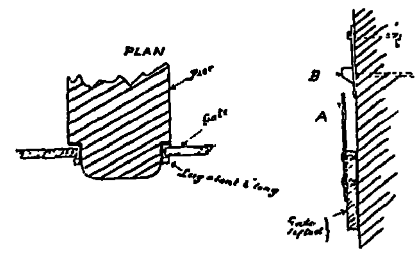
FYZABAD DAM, EASTERN JUMNA CANAL.



HEAD BUNDS ON THE GANGES CANAL, LOOKING UP-STREAM.

[To face page 128.

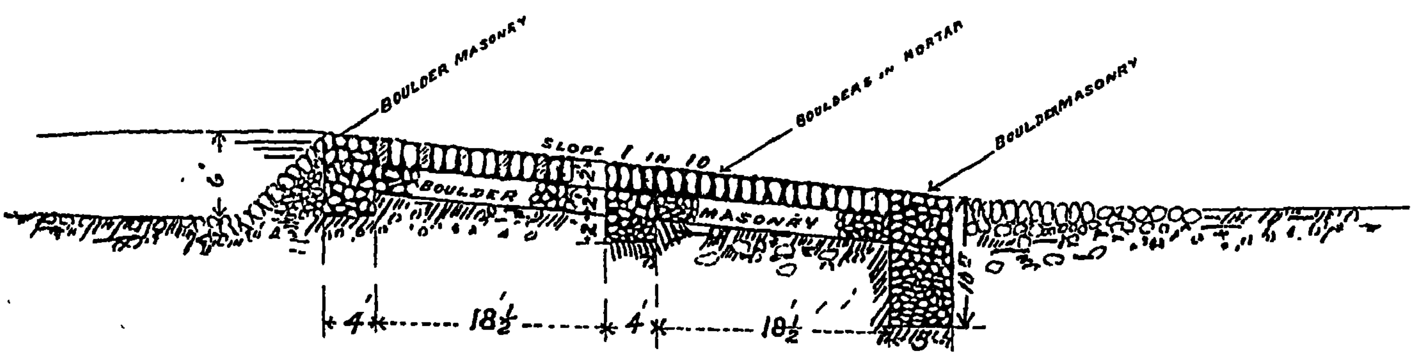
The sill of the head-sluice of the Western Jumna Canal is 4 feet above the under-sluice floor and 4 feet above the canal bed, a measure which is designed to prevent the flow of boulders into the canal. The floor has a slope of about 1 in 10 from the sill to the canal bed. There are thirty-five openings of 6 feet, and the piers are 3 feet 6 inches thick. The gates are of timber, worked by a traveller above. The gate grooves are peculiar, as shown in the sketch; they are of iron, with only little lugs in front to retain the gate. The head-sluice gates are hung, when they are lifted, by a piece of flat iron attached to the gate: the flat iron A has a slot cut in it which fits on to the catch B. The gate has sufficient play to enable the flat iron to be moved on and off the catch, and it is only necessary to push the flat iron off this catch and the gate falls. There are chains permanently attached to each gate for lifting it; these, when the gate is hung on the catch B, are hooked on to staples in the wall, so that they are clear of the gate when it falls.



GATE GROOVES OF THE HEAD SLUICE, WESTERN JUMNA CANAL.

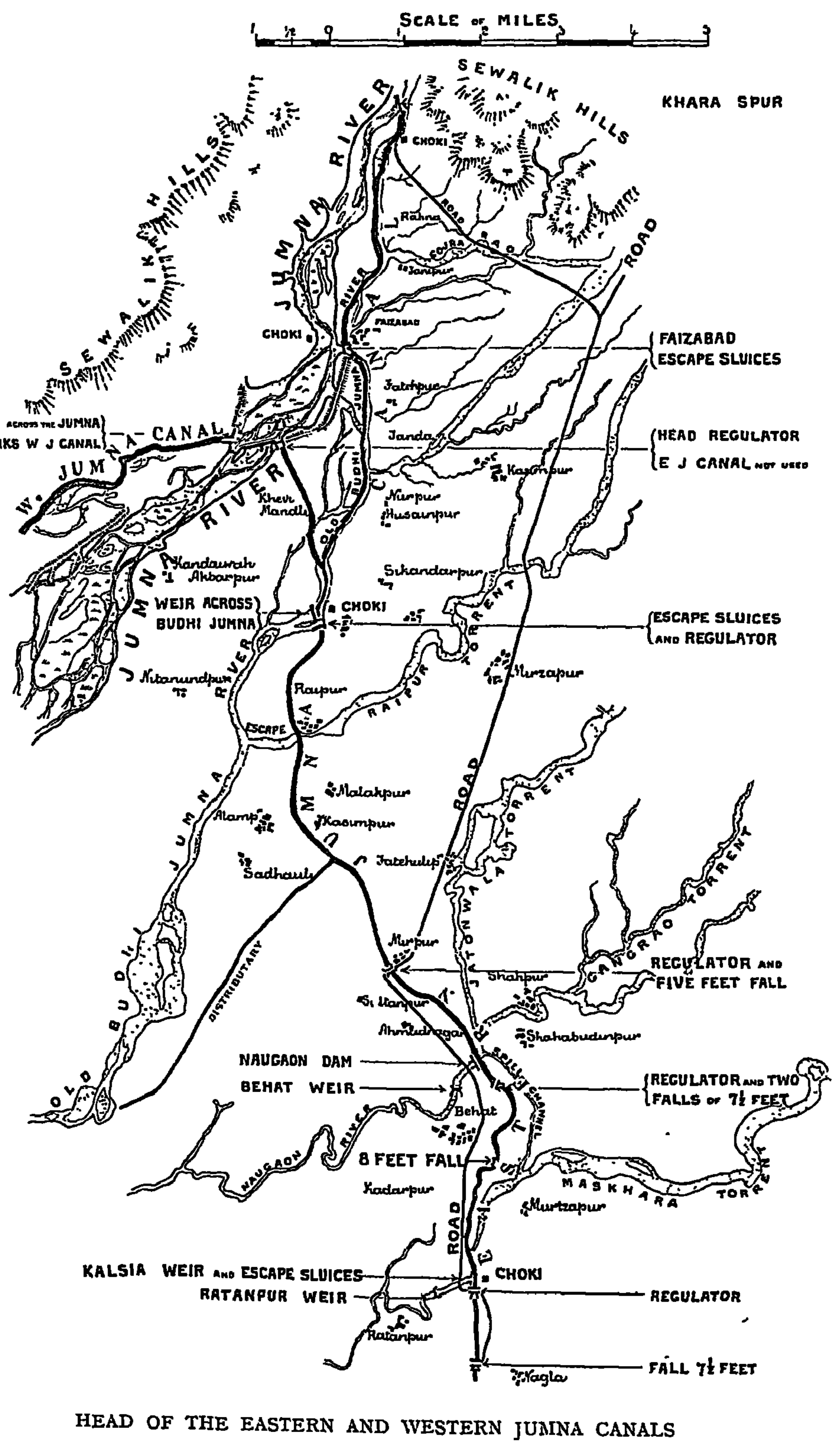
The weir itself is similar in construction to the Ravi weir, except as regards the depths of the foundations, the cross section is shown in the following sketch. The crest of the weir was raised 6 feet above the general level of the river-bed, but the bed above has filled up with shingle, and at least half the weir is now covered with boulders and shingle over the top of the crest; it is covered in this manner more or less at each end, but the centre is clear. It is sometimes necessary in the cold weather to make a cut through the heavy shingle deposits above the weir, to lead the water of the river to the head-sluice, even although the sill of the head-sluice is nearly 8 feet below the western end of the weir, a fact which shows how powerless under-sluices are to influence the stream of a river for any great distance above them.

The supply of the Eastern Jumna Canal was originally drawn from the river near Faizabad Plate on page 130), but in 1834 the bed of the river near this point retrograded to such a



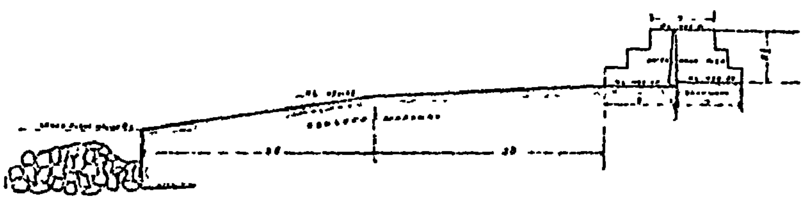
CROSS SECTION OF JUMNA WEIR.

degree that the source of supply was removed to Khara, and a dam was constructed at Faizabad across the channel which used to supply the canal. The channel from Khara to Faizabad is a portion of the bed of the old Budhi Jumna river, which had only to be excavated near the head at Khara to make it suitable to carry the supply of the canal. In order to force the discharge of the river, or so much of it as may be required, into this channel, a spur is run out every year into the river near Khara immediately below the off-take. The spur is made in October or November, and is destroyed every year by the first or second flood in June and July. During the flood season the supply drawn in at Khara is more than ample, and a large volume of it has to be returned to the Jumna, either over the dam at Faizabad, or over a corresponding dam at Naushera, across the Budhi Jumna river, which forms a flood escape for the upper



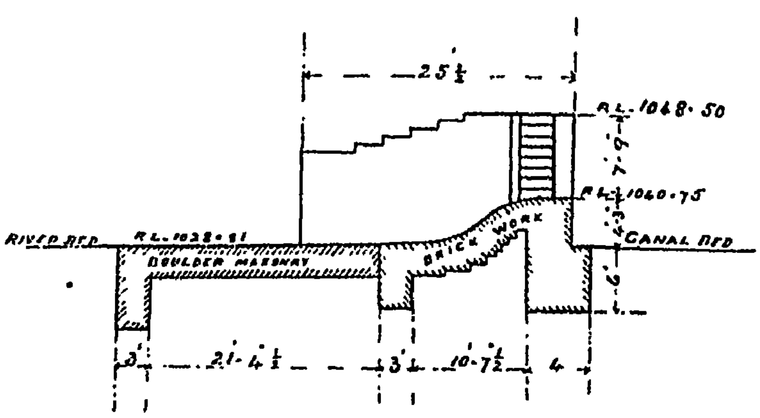
HEAD OF THE EASTERN AND WESTERN JUMNA CANALS

channel. At this point, Naushera, just below the dam, there is a regulator across the canal, by which its discharge is controlled. The upper, or Faizabad Dam, is situated about two miles above the permanent weir across the Jumna, which is the head of supply for the Western Jumna Canal, and any water which is returned to the river from the Eastern Jumna Canal flows down to the permanent weir, and is available for the Western Jumna Canal. It thus occurs that the Faizabad Dam is used, when the river is very low, to aid in the division of the total available discharge between the two canals: the total supply at such times is divided in the proportion of one-third to the eastern, and two-thirds to the western canals. If the action of the Khara spur at the head of the eastern system forces a larger proportion than one-third of the total volume into that system, the shutters or the *kurries* in the Faizabad Dam are opened, and an increased supply is sent down the river to the head-works of the other system. The Khara spur must be made up to a certain point, or the eastern system will not get its proper share of the water; so the length of this spur is primarily the dividing power, and the Faizabad Dam is used to correct minor inequalities.



SECTION OF THE ESCAPE SLUICES AT FAIZABAD, EASTERN JUMNA CANAL.

The Faizabad Dam appears to play an important part in flood time; it acts as an under-sluice, and takes back to the Jumna a considerable volume of water. It might be expected that the channel from Khara to Faizabad would have become filled up with boulders and shingle, but this is not the case, although there must be a flow of shingle down the river bed itself, and probably down the canal channel also. The slope of the channel is about 13 feet a mile from Khara to Faizabad, and 16 feet from Faizabad to Naushera, and it is thought that the fact that the channel does not deteriorate is due to the action of the two escapes, which carry back to the river the shingle which enters at the head. It is certain that a considerable amount of heavy detritus does pass over the Faizabad Dam, for the floor is injured and cut about by the flow of boulders.



SECTION OF WEIR AT NAUSHERA, EASTERN JUMNA CANAL.

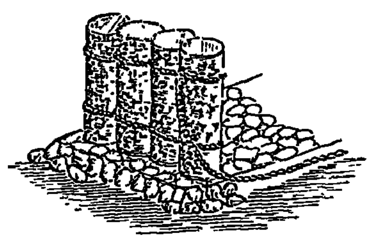
The Faizabad Dam consists of a weir, with piers above it; the piers are 6 feet above the weir crest. There are twenty openings of 10 feet. In each opening a gate is hinged at its lower edge on the floor; the gates are held up by let-go gear, and when released they fall down-stream and lie on the weir crest in flood time. There are grooves above the gates in which *kurries* or horizontal baulks can be inserted. The sketch above gives an idea of this work.

The Naushera Dam has a different section, as shown above; it is not subjected to such heavy floods as the Faizabad Dam, and the depth of water on the crest rarely exceeds 5 feet.

The spur at Khara, which really forms the head-works of the Eastern Jumna Canal (which irrigates some 300,000 acres of land) costs a trifling sum—something like 1,000 rupees—yearly. It is made of gabions full of boulders. The gabions are constructed of green twigs

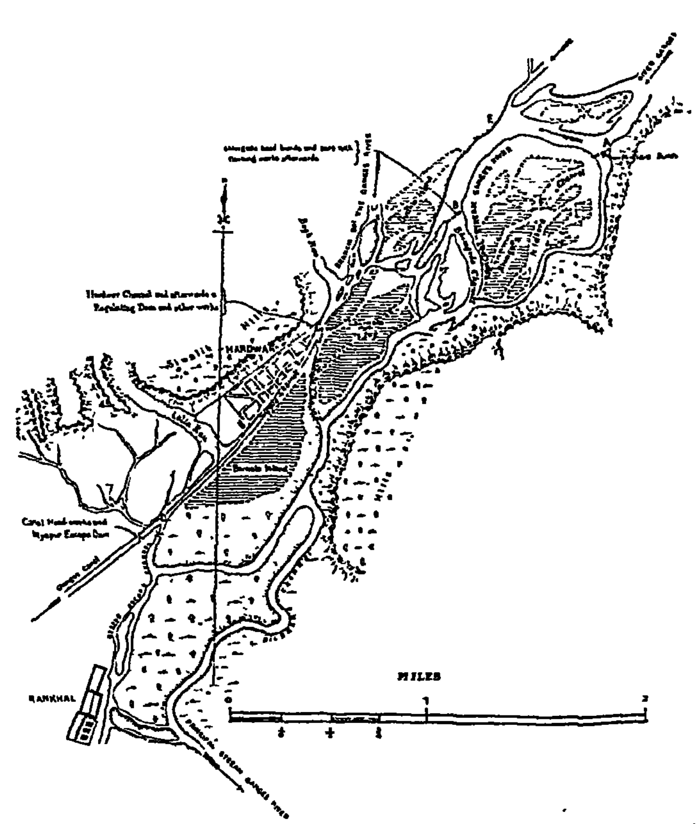
bound together with rope made of green grass; they are about 5 feet high, and 2½ to 3 feet in diameter. Four of these gabions are bound together with strong rope, also made of green grass, and, the lower ends of them being closed up with a network of twigs and rope, they are taken to the end of the spur and stood on end, as shown in the sketch below.

A strong rope, perhaps 3 or 4 inches in diameter, made of the same grass, which grows near, is attached to the group of four gabions, and made fast to other ropes at a point perhaps 30 or 40 feet from the end of the spur where the gabions stand. They are then filled with boulders and the tops are strongly bound over. The group of gabions is then upset by a body of men, and they fall over into the water. The stream is so strong that they would be swept away but for the rope by which they are attached to each other and to the other ropes of previous groups of gabions of which the spur is made up. In this manner the spur is advanced in 9 or 10 feet of water flowing at a velocity of 10 to 12 feet a second.



GABIONS IN THE KHARA SPUR

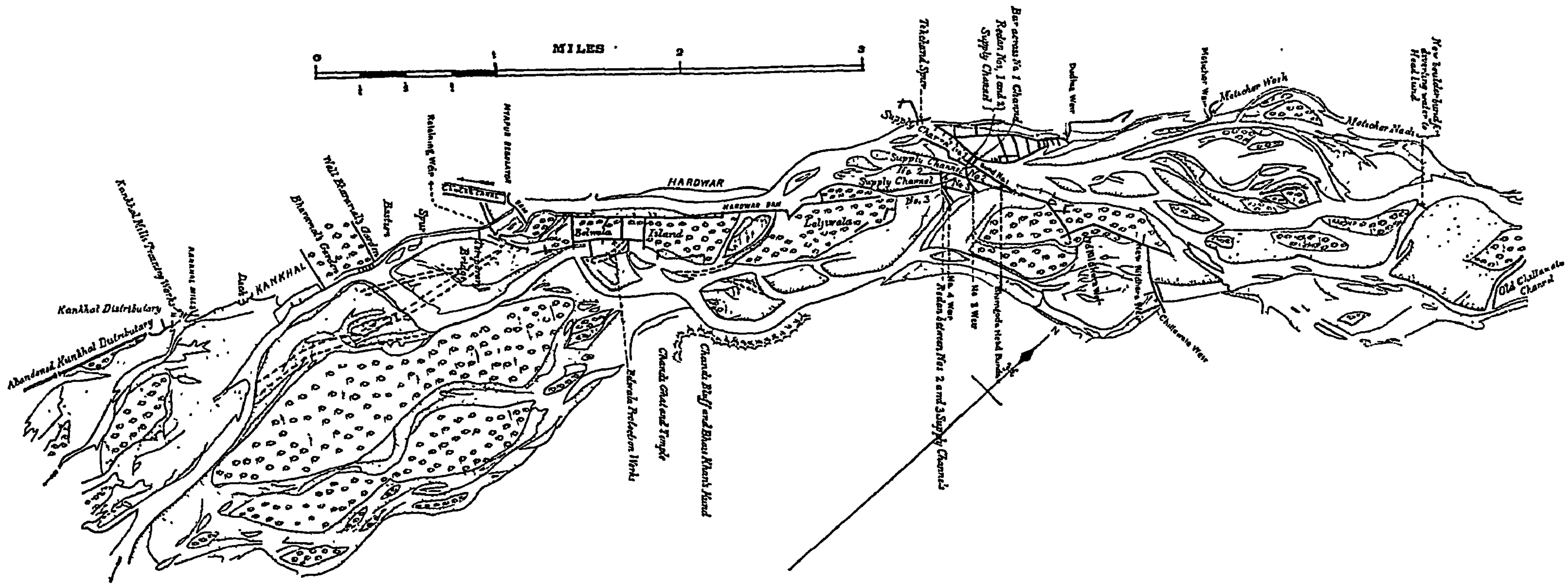
The Ganges Canal, which carries a maximum discharge of 6,800 cubic feet a second, is supplied in a manner which has features in common with the system employed on the Eastern Jumna Canal. The supply, in the dry season, is forced into a side channel by temporary dams, and there are escapes from this channel back to the main stream of the Ganges. The head-works of this great system of irrigation are situated close to the hills where the river runs on beds of boulders, with a fall of some 10 feet in the mile. The Ganges at this point consists of several channels, which have changed considerably since the Ganges Canal was originally opened, and which are constantly changing, more or less, every year. The works for leading the supply into the canal when it was first opened are shown in the sketch.



THE EARLIEST RIVER WORKS OF THE GANGES CANAL.

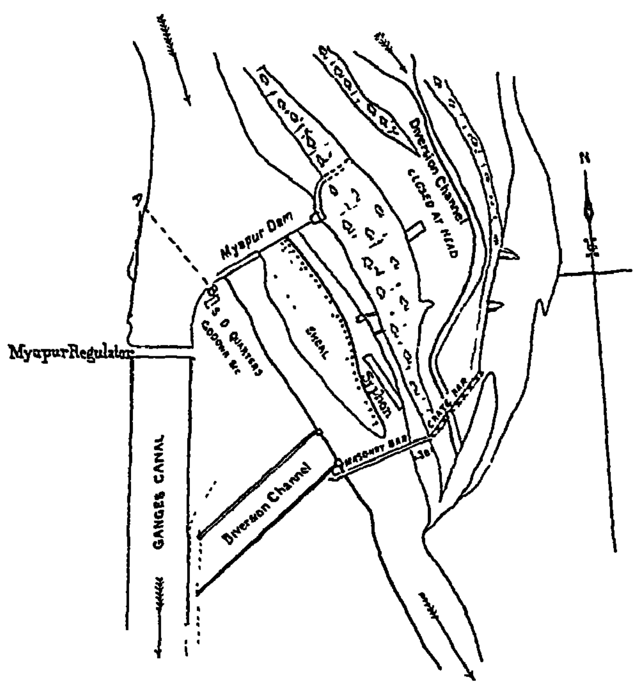
Hurdwar,[1] on the right bank of the river, is one of the holy places on the Ganges most sacred to Hindoos, and it was essential, on this account, that the bathing-places should not be interfered with. The channel passing the sacred ghâts was chosen as the supply channel to the canal. The channel was, indeed, favourable for that purpose, and it was conveniently developed by joining up the three islands, Bhimgoda, Laljiwala, and Belwala by boulder bunds, as at A and B. The required supply was turned in above the highest island, and the escape of it back into the main river was prevented by the bunds. This was the first simple forms of the works, but, in the

[1] Note by Mr. Hutton, Superintending Engineer.



RIVER WORKS IN THE GANGES IN 1898, AT HEAD OF THE GANGES CANAL.

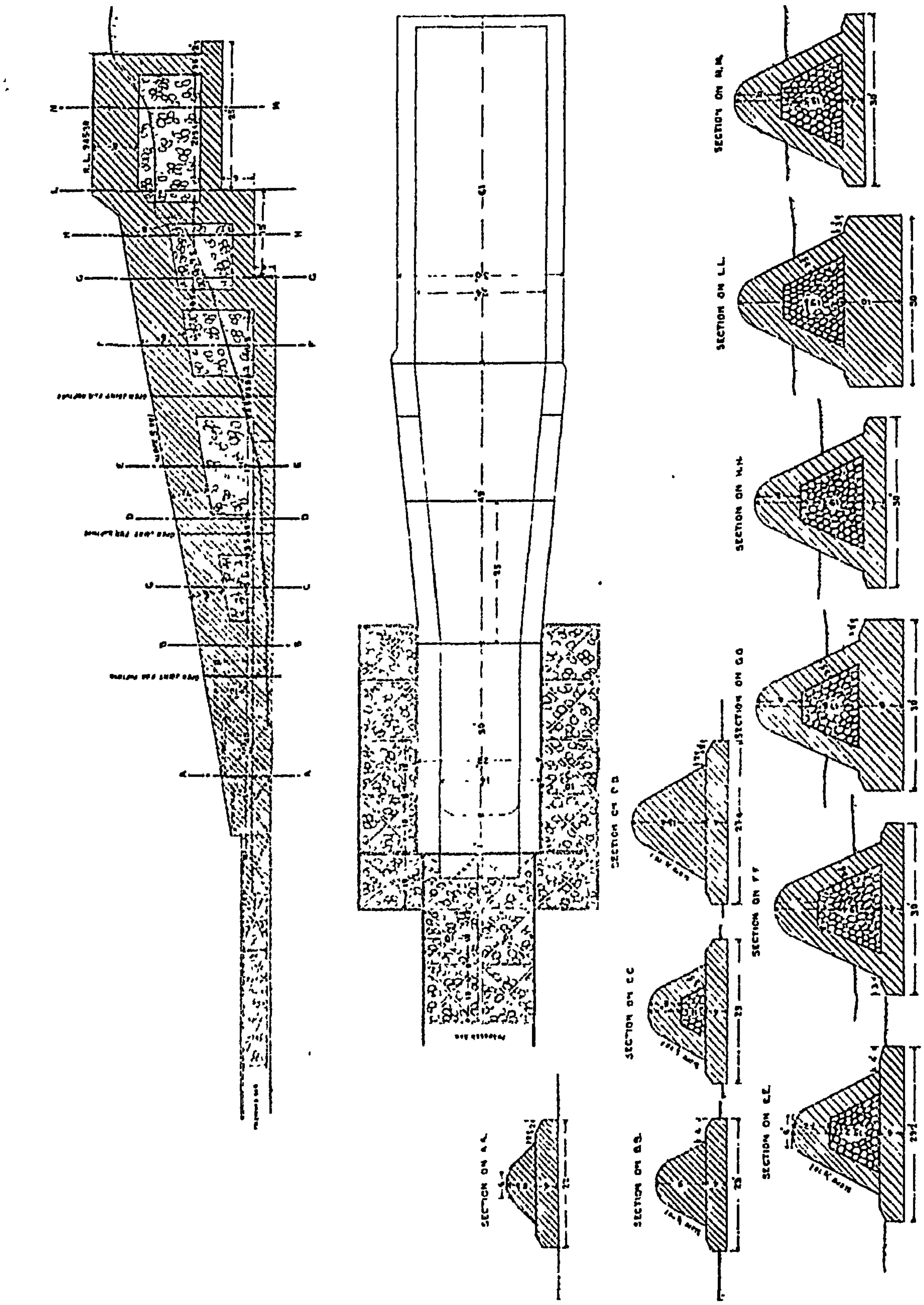
last fifty years, they have been greatly extended. Every addition was forced on the engineers by the necessity of a larger supply, or for better regulation. It was very soon found necessary to erect the regulator at C (page 132), which now goes by the name of the Hurdwar Dam. The channel below A scoured out to a dangerous degree, and threatened to become the main channel of the river; this necessitated the construction of two permanent weirs, called the Nildhara and Chilla weirs. The channel below B also scoured out; it was maintained by a series of weir bars which were built across it. The Myapur Dam at D (page 132) proved too small for its work; it was enlarged and improved. Floods began to cut at the point E; spurs were erected at that point. The eastern half of Belwala island was eroded in the course of years, and when at length the floods set heavily on its crumbling face, massive groynes were erected to stop the erosion. Under the influence of all these causes the river bed above the head of the Ganges Canal, for 5 miles and more, has become a series of weirs, regulators, bunds, groynes and revetments, which regulate the the flow of the waters. These works are indicated in the sketch on the previous page.



Head of Ganges Canal.

During the fifty years that these works have been gradually extended and developed, the boulder beds of the channels have shown a marked retrogression of levels both below the head-bunds at Bhimgoda and below the Hurdwar Dam. It has proved necessary to strengthen the works and to replace the spurs, made of boulders in crates, which were first used, by groynes of boulder masonry and concrete. The sketch on next page shows the details of construction of the new Belwala groynes. They are made of separate cells of masonry with boulder cores; each cell weighs about 100 tons, and, if the groyne breaks up, each cell is of sufficient weight to hold its own against the current, and to form a foundation on which, in a subsequent year, an even stronger groyne can be erected.

The Hurdwar Dam and the Myapur Dam are the two escapes which discharge any surplus water flowing in the Hurdwar channel, which is not required for the canal. In flood times as much as 60,000 cubic feet per second is escaped over the Hurdwar Dam, and 30,000 over the Myapur Dam. There is, consequently, a large and sudden reduction in the discharge of the Hurdwar channel just below the Hurdwar Dam, which results in a heavy deposit of shingle in the bed. This has to be cleared every year at considerable expense. The Hurdwar Dam has six bays of 176 feet each, giving a total length of 1,056 feet of lineal waterway; the dam is fitted with 132 drop-gates 8 feet wide by $4\frac{1}{4}$ feet deep. The Myapur Dam, when the canal was first opened, was 517 feet long, with small vents 10 feet wide between the piers. The dam now consists of seven bays of 20 feet and 272 lineal feet of spill weir, with a crest $6\frac{1}{2}$ feet above the floor level of the 20-feet vents. This spill weir has gates which are left open in flood time, and the regulation of the discharge is effected by the 20-feet openings. The 20-feet scouring bays have proved effective, both in reducing the shingle deposit above the Myapur regulator, and in affording a fairly free passage to the trees



GANGES RIVER TRAINING WORKS, SPUR HEAD, 1898.

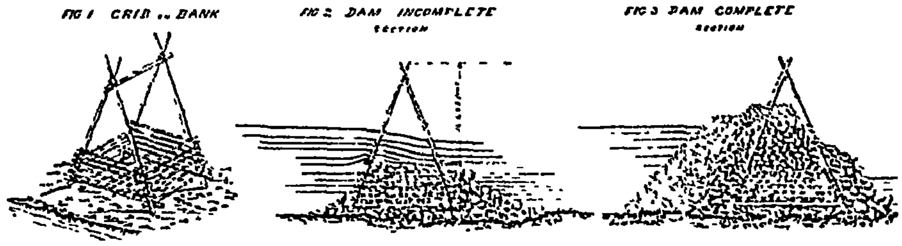
and driftwood, which are swept down by the river in flood time. But, during the great flood in the Ganges, caused by the bursting of the Gohna Lake in 1894, four of these vents became blocked.

The head-sluice of the canal is situated on the canal itself, about 350 feet back from the line of the Myapur Dam.

The deposit of shingle in the bay above the regulator, up to the line A B, used to be so serious that the construction of a new regulator on that line was contemplated. The alterations in the Myapur Dam itself have, however, obviated the necessity of this.

During the months of December and January the Ganges is at its lowest; the discharge then is generally about 5,000 cubic feet, and may be as little as 3,800 cubic feet a second. The river generally begins to rise during the first week in May, when the snows of the Himalayas begin to melt, and during the months of May or June all temporary bunds across the river are swept away. Although they are constructed of boulders and shingle in crates, they crumble away like sugar under the force of the current, and have to be reconstructed in the following September and October, when the river has fallen. They are usually completed about the 15th to the 20th of November. When the river is low the entire discharge of it is forced by the Chillawala weir towards the right bank of the river. At Bhimgoda the channel which leads towards the left bank is annually closed by three temporary bunds. The leakage

FIG 1 CRIB ON BANK — FIG 2 DAM INCOMPLETE SECTION — FIG 3 DAM COMPLETE SECTION



CRIBS USED IN THE CONSTRUCTION OF TEMPORARY DAMS, GANGES CANAL HEAD-WORKS.

through No. 1 is stopped by No. 2, and the leakage from No. 2 is almost entirely stopped by No. 3. From above each bund there is a supply channel leading towards the right bank of the river. In this way the entire discharge of the Ganges is forced into the Hurdwar channel, and as in the month of November the discharge is usually much more than is required for the canal, the surplus is passed back into the river through the two dams or escapes, which have already been mentioned.

The construction of these temporary dams is a work of some magnitude in a stream having a surface slope of 10 feet or more in the mile, and in water which, in the case of No. 1 dam at any rate, is from 10 to 20 feet in depth. No. 2 dam is always less difficult to make than No. 1; sometimes it has to be made with cribs, but generally it is only an embankment of boulders and shingle. No. 3 is always a shingle dam. A number of cribs are first made on the foreshore of the river[1]; these are each about 10 feet in length, Fig. 1, and they vary in bottom width according to their vertical height, which has to be adjusted to the depth of the stream in which they are to be placed. The first operation in the actual construction of the dam is to get a 14-inch coir rope across the river. This is done by the help of ropes of different sizes, which are pulled across, one after the other, until one of sufficient strength is available to deal with the heavy rope. When the 14-inch rope is across the stream it is propped up, 20 to 25 feet above the water, at various points on groups of piles standing on the river bed, and between these supports it hangs down to within 8 or 10 feet of the water, the ends of it being firmly lashed on

[1] "Roorkee Professional Papers," 2nd series, No. cclii., vol. vii.

shore. Snatch blocks are run on each bight of the 14-inch ropes, which can be manipulated backwards and forwards on the rope by small windlasses on either bank. To these snatch blocks, ropes are fastened, to which boats can be attached, so that a boat can be pulled backwards or forwards, and placed at any point of the river. A barge, fitted with a derrick in the stern, first picks up one of the cribs which hangs over the stern of the boat in the water, the weight of it is counter-balanced by a quantity of boulders which are placed in the bow, the boat is then attached to a snatch block, and is pulled into the required position in the river. When the crib hangs in its right position in the line of the dam it is gradually lowered by the derrick into the water, and the boulders are taken from the bow of the barge and dropped into the crib as it descends; other smaller boats are also dropped alongside, from which other boulders are placed in the crib sufficient to sink it to the bottom. When it is settled into its proper position it is firmly lashed to the neighbouring crib, which has been sunk before it, and a few more boulders, making a total depth of 3 or 4 feet perhaps, are filled into it so as to make it secure. The derrick boat is then pulled back to the shore by means of the snatch block running on the 14-inch rope, where it picks up another crib, which is sunk in the same way next to the last one and secured to it. In this way a line of cribs is placed right across the river or across the deeper part of it where the velocity is too great to enable a dam of boulders alone to be made. The water runs over the top of the boulders in the cribs, as shown in Fig. 2, and the dam is a submerged weir. The dam is then raised, foot by foot, by boulders which are dropped into the cribs from boats which are first pulled out one after another, by means of the snatch blocks, and the dam gradually rises up to the surface of the water; the crest of the dam is kept as near as may be at a uniform level, so that the water flows evenly over the top of it. When the crest is above water there is, of course, copious leakage through the boulder dam. At this stage grass *tattees* or mattresses made of long bundles of grass, 6 or 8 inches in diameter, or of thin twigs lashed together by ropes, are placed in front of the dam as shown in Fig. 3. A pole or *bullah* is lashed to the lower edge of this mattress, and, behind this, boulders are placed on the mattress until it is sunk into position: it is important to allow the mattress to rest for a width of about 10 feet on the river bed, as this is the point where the greatest amount of leakage appears to occur. On the top of this mattress a berm of small boulders and shingle is thrown, by labourers walking along the crest of the dam, until it has been made as strong and as staunch as is considered necessary. There is always a stream flowing along the face of No. 1 dam, and the consistency of the shingle berm depends on the velocity of this stream. No. 2 dam is also constructed in the same manner, or a portion of it, but No. 3 is a boulder and shingle dam, no cribs being necessary. As the current in front of these lower dams is much less than that above No. 1, they can be made of finer material, and therefore are more water-tight.

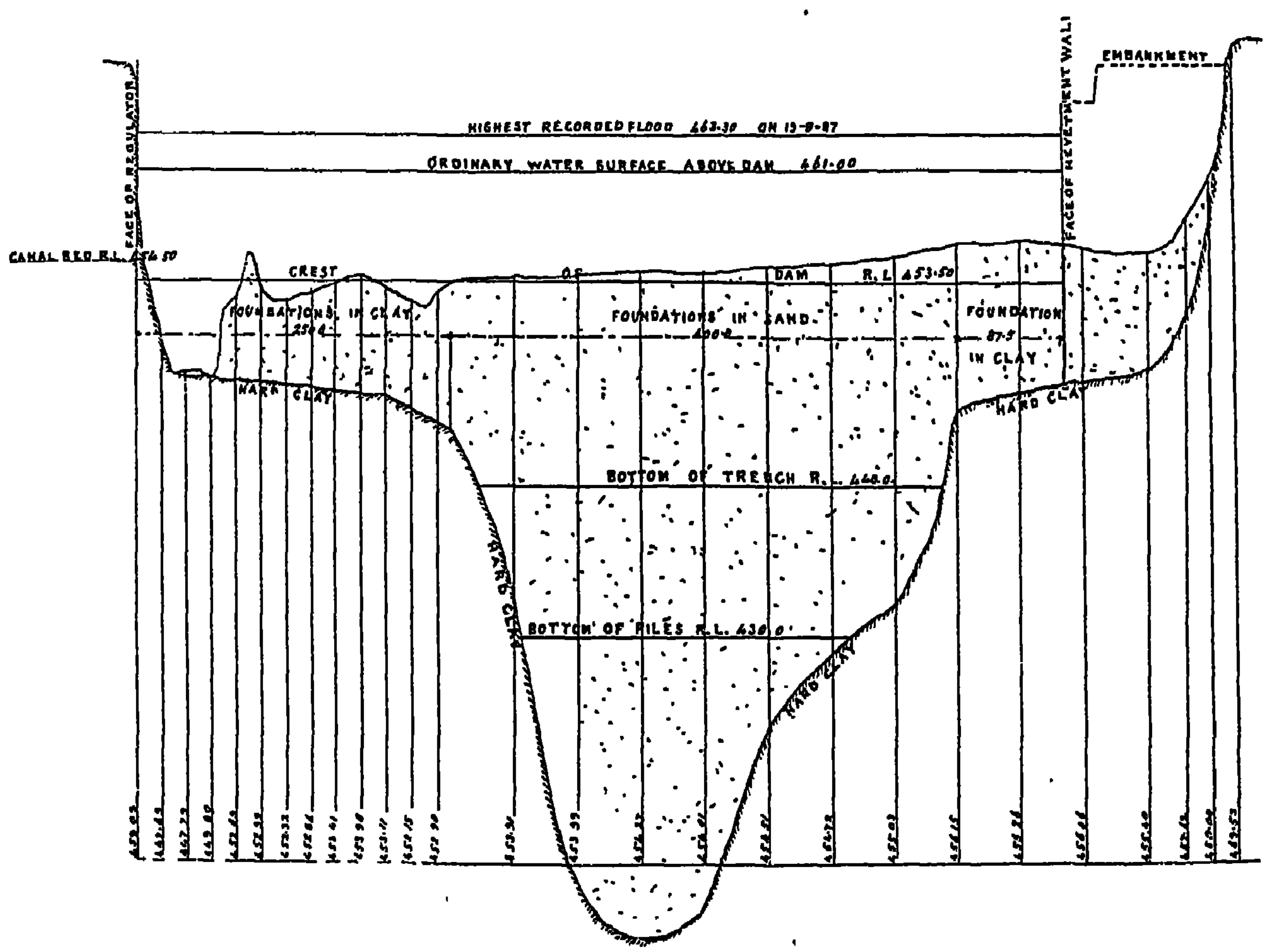
The total maintenance charges for these river works at the head of the Ganges Canal aggregated Rs. 17,37,000 in the twenty-five years ending in 1898, or about Rs. 70,000 a year; the cost of annually constructing the head-bunds at Bhimgola is about Rs. 35,000, or half the gross annual expenditure.

CHAPTER IX.

HEAD-WORKS IN CLAY AND COARSE SAND.

Sidhnai Canal Weir on the Ravi River—Weirs on the Mahanuddee in Orissa—Centre Sluice of Mahanuddee Weir—Mahanuddee Under-sluices—Panchkoorah Weir—Breach in the Mahanuddee Weir—Weirs in deep Sand—Kistna Weir in Madras—Godavery Weir—Coleroon Weir—The Sone Weir in Bengal—Closing Centre Sluices of Sone Weir—Under-sluices of the Sone Weir—Sirhind Canal Weir across the Sutlej

An example of a weir of Class IV.[1] is found in the needle dam across the Ravi river at the head of the Sidhnai Canal. This canal lies near Multan, in the Punjab. The slope of the river bed is 0·083 per thousand (about 5 inches a mile), and the velocity of the stream in floods



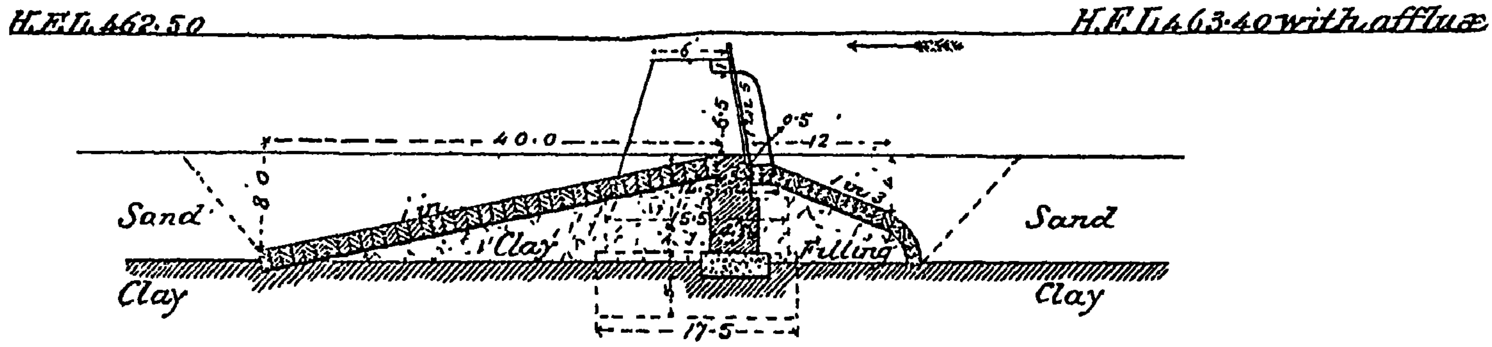
Section of Ravi River at Site of Sidhnai Weir.

is only about 2½ feet a second. The discharge of the Ravi at this point rarely exceeds 12,000 cubic feet a second in floods, so the weir is a small one. A cross section of the river, on the line selected for the weir, is given above. The section shows that there was a good clay foundation for a length of 200 to 250 feet on each side, at a reasonable depth below the level fixed for the crest of the weir, but that in the centre of the river the clay gradually sank to 40 and 45

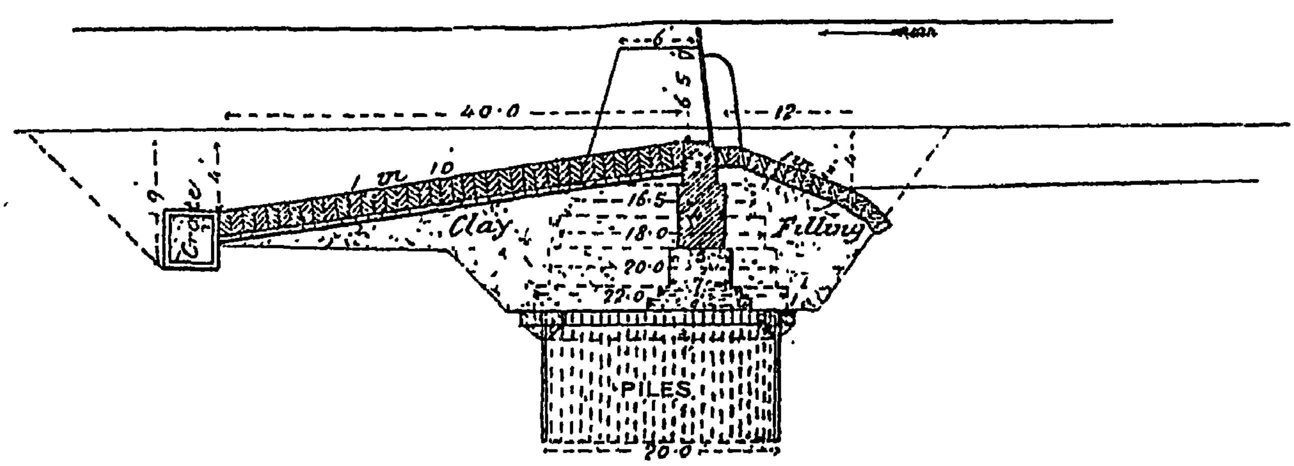
[1] See page 109.

feet below the level of the crest. To carry the foundations down through the sand to this depth would have been very costly, but, as the supply of the river ran very low at certain times of the year, it was desirable to make the weir as water-tight as possible, so that the entire discharge might be utilised in the canal. The weir has been constructed as shown in the cross sections given below: when the clay was at a greater depth than reduced level 440·00 (the crest of the weir being 453·50) a trench was excavated in the sand to 440·00, and, below that level, sheet piling was driven in two lines 20 feet apart parallel to the centre of the dam, with cross lines

SECTION ON CLAY



SECTION IN SAND



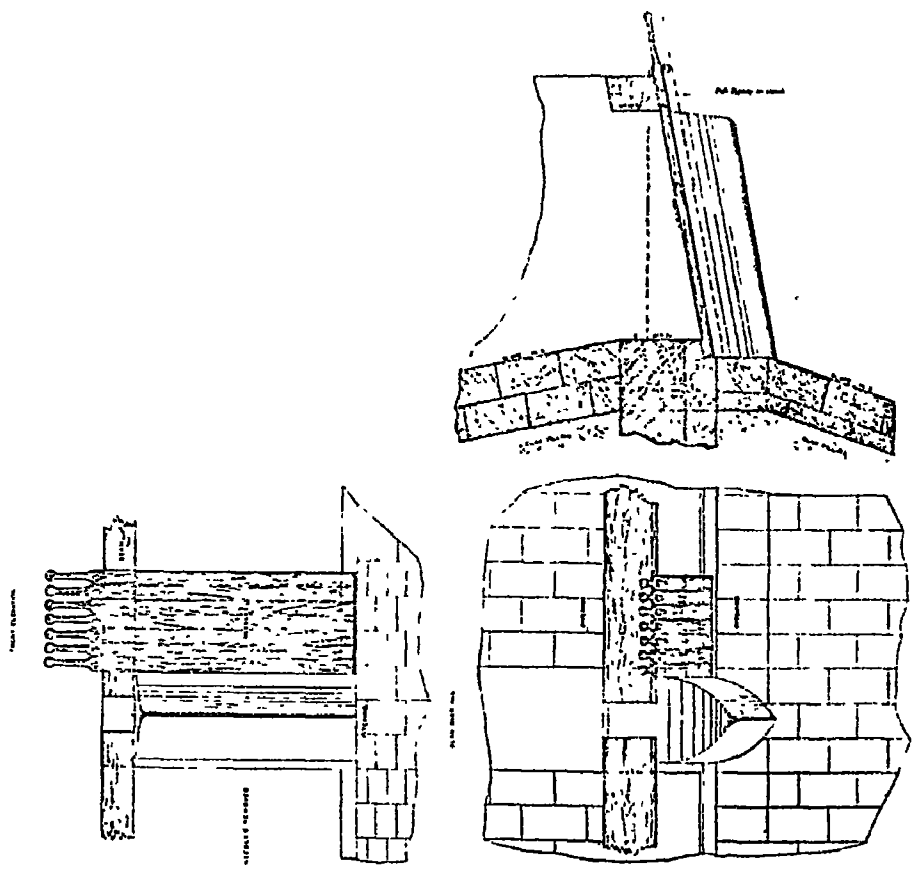
SECTIONS OF SIDHNAI WEIR ON THE RAVI RIVER.

7 feet apart, at intervals of 23 feet, to act as boxing for pier foundations. These piles prevent the excessive percolation through the sand below, which would have been caused by the considerable difference in level (7 to 8 feet) which exists in the dry season between the water above and below the weir. As soon as the piles were driven, the foundations of the piers and body wall were built in concrete, and the trench was filled up with clay, the surface being pitched with brick blocks (2 feet by 12 inches by 10 inches), with a slope of 1 in 3 on the up-stream, and 1 in 10 on the down-stream face. The crest level of the weir (453·50) is 1 foot below the bed level of the canal, and is also below the general level of the sand of the river bed, so the weir is practically all below ground except the piers, which are constructed right across the weir at intervals of 20 feet in the clear. The weir is consequently not subjected to any scouring action of importance.

The low surface slope, small depth, and small velocity of the floods rendered the construction of this simple weir possible. It is a successful example of a weir of extremely light section.

The entire length of the weir is 737 feet. Between the piers timber beams are fixed, and the openings are closed by vertical needles of deodar wood, $7\frac{1}{2}$ feet long by 5 inches by $3\frac{1}{2}$ inches, with a handle 18 inches long above, as shown in the sketch below.

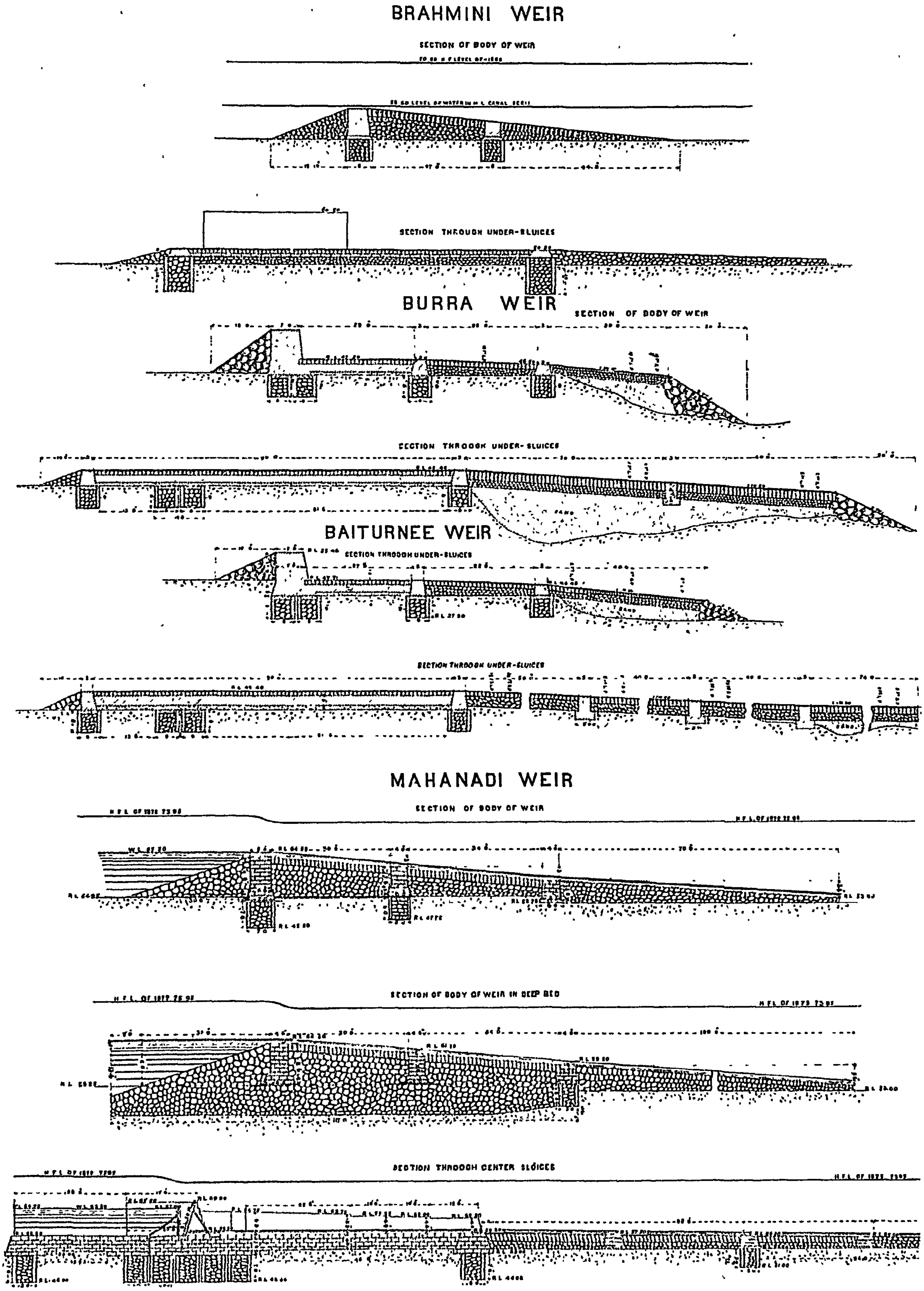
This weir has no under-sluices on account of the low level of the crest. It has been proved to be most efficient. The needles are easily manipulated and made water-tight in the following manner:—The needles having been dropped into position and wedged as close together as possible, the men proceed to staunch the interstices between them. This is done by means of a small cup-shaped wicker basket attached to the end of a long bamboo, and a mixture of sawdust, dry cow dung and litter. Taking a basketful of this mixture the khalassy, who is standing on the bridge over the needles, applies it to the up-stream face of the dam, sweeping the needles with an up-and-down motion until the current has carried the rubbish into the interstices. The leaks are at once staunched, and in an incredibly short time the dam is rendered completely water-tight. The bamboo to which the basket is attached is of sufficient length to enable the operator to reach the lowest part of the needles.



NEEDLE WEIR ACROSS THE RAVI RIVER, SIDHNAI CANAL.

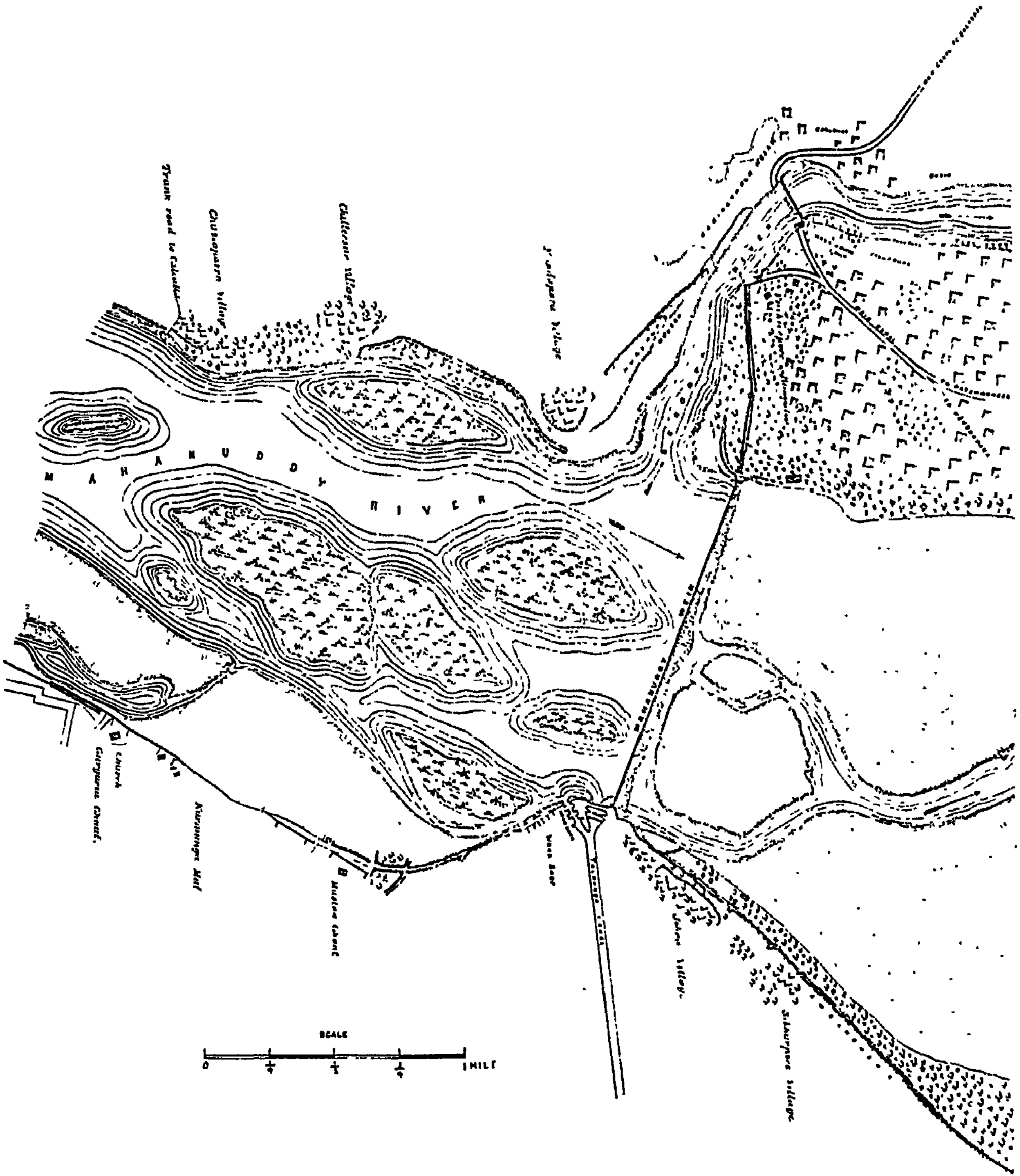
The Plate on the opposite page shows cross sections of different portions of several weirs constructed in connection with the irrigation system in the delta of the Mahanuddee river in Orissa. The beds of the streams are generally in deep sand, but in some cases stiff clay, and in others laterite rock, which underlies the sand, rises to the surface. The object of the Mahanuddee weir was to raise the water of the river during the dry weather to a sufficient height to give a depth of 8 feet in the canals: this was accomplished by the construction of a weir with folding shutters 3 feet high on its crest. The total length of the weir is 6,400 feet, and it is calculated to discharge about 900,000 cubic feet per second in high flood; its crest is 64·50 above mean sea level, or 13 feet above the average summer water level of the river.

The weir is provided with two sets of scouring sluices, one in the centre and one at its southern extremity; the former divides the work into two parts. The portion of the work



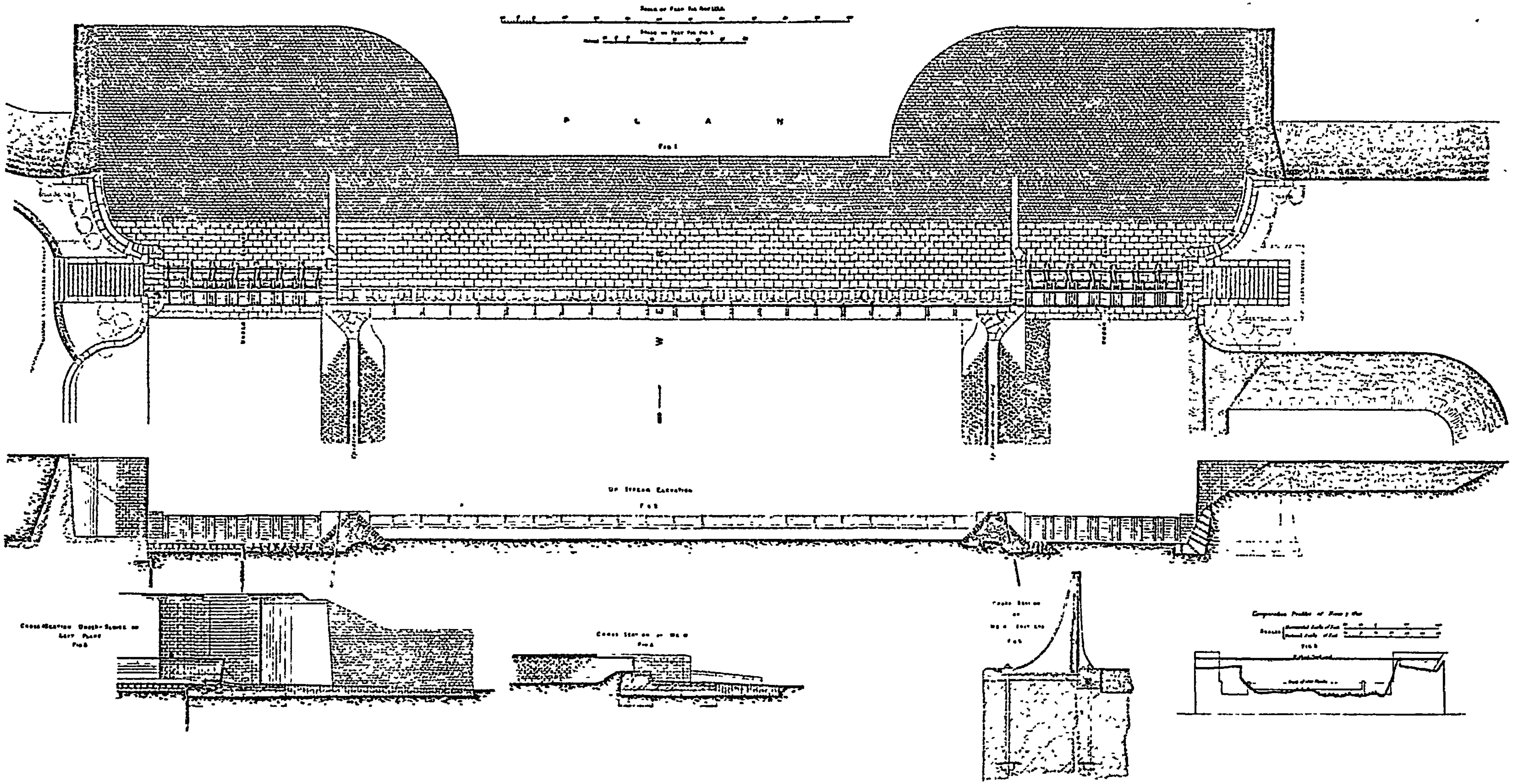
WEIRS ON THE RIVERS IN ORISSA.

north of the centre sluices is 2,950 feet in length, and is composed of a breast-wall 12½ feet in height, 7 and 8 feet wide at bottom, and 4½ feet at crest, founded on wells from 7 to 9 feet in depth, with the exception of a length of 826 feet, which is founded on clay. At a distance of



SITE OF MAHANUDDEE WEIR IN ORISSA.

30 feet from the breast-wall there is a second wall parallel to it, 5 feet wide at bottom and 4 at crest, and of a height corresponding to the rear slope of the weir, which is 10 to 1; it is founded in the same manner as the breast-wall: the interval between these walls is solidly packed with large picked rubble stone, each stone being about 2 to 2½ cubic feet; the lower wall is protected



PANCHKOORAH WEIR ON THE MIDNAPORE CANAL IN BENGAL.

by a rough stone apron in continuation of the slope of 10 to 1, and was originally made 55 feet wide at its narrowest part, but additions have been made to this width from time to time.

The southern portion of the weir is 2,600 feet in length, and constructed in the same manner as the northern part, with an addition of a third parallel wall at a distance of 34 feet from the second one: the same kind of rough stone apron as in the northern portion protects this third wall. The two first walls are founded partly on wells and partly on stiff clay. The third wall is founded on rubble stone.

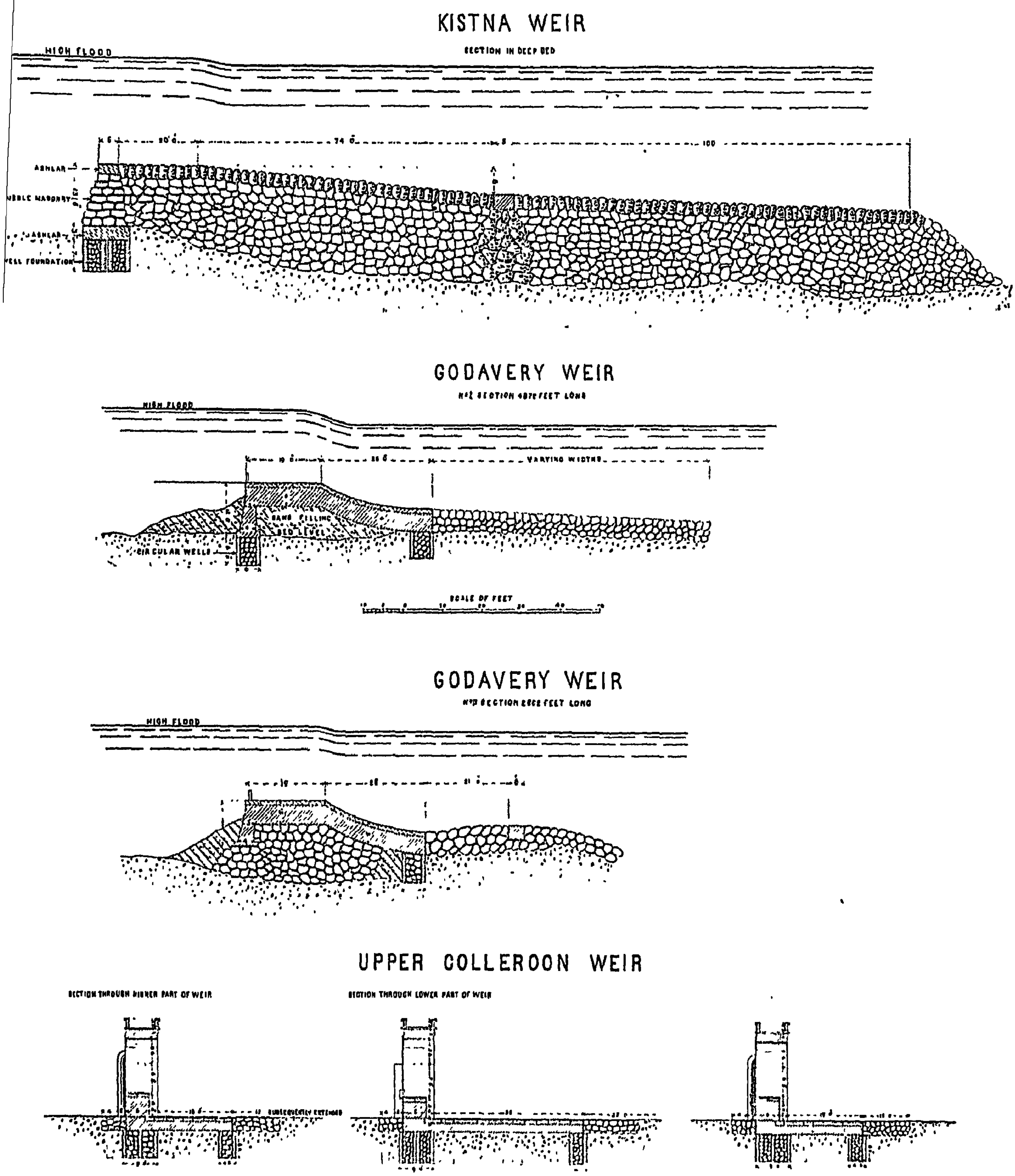
The face of the weir along its whole length is protected by rubble stone packing, with a base varying from 20 to 40 feet.

The centre sluice is divided into ten bays, each 45 feet in width and 500 feet in all, including piers: each bay is provided with double wooden shutters (see Plate on page 183): the flooring is of cut laterite and rubble masonry 4 feet in thickness, 115 in length, and 150 in breadth; and this is further protected by a rough stone apron 600 feet in length and 4 to 6 feet in thickness, divided into four parts by three parallel walls to prevent the packing from being carried away by the velocity of the current. Above the sluices there is also a rough stone apron about 30 feet in length and 600 in width, and from 4 to 5 feet in thickness. The sluice is connected with the body of the weir by flank walls. The whole of the work with the exception of the lower apron wall is founded on wells in sand.

The under-sluices on the Mahanuddee weir consist of 38 vents, each 5 feet in width, giving a clear waterway of 190 feet. The total length of sluice from flank wall to abutment is 344 feet: the length of the flooring is 115 feet of cut laterite and rubble masonry 4 feet in thickness, supported by a rough stone apron 110 feet in length, from 1½ to 6 feet in thickness, divided into three parts by two parallel apron walls: there is a similar protection up-stream, 30 feet in length. The piers and curtain walls were built partly on wells and partly on clay; the abutment and wing walls on stiff blue clay; the flank wall connecting the sluice with the weir was founded entirely on wells.

A breach occurred in the centre of the Mahanuddee weir in 1886, at the site of the centre sluices; about half the centre sluices were carried away, besides a portion of the weir, and a deep hole was scoured out on the line of the weir and below it. The cause of this failure was never satisfactorily explained, but it is supposed that leakage occurred, below the floor of the under-sluices, between the wells in its foundation, and that a stream was created below the floor which gradually undermined it. When a strain was thrown on the floor, during the early part of the flood season, it collapsed, and a breach 300 or 400 feet in width was soon scoured out by the current. The repairs of this breach, which took two years to complete thoroughly, cost about Rs. 250,000.

The Plate on page 143 shows the weir at Panchkoorah on the Midnapore Canal in Bengal, where the nature of the foundation is very similar to that in Orissa. The under-sluices are fitted with gates similar to the Orissa ones (page 183). It will be noticed that this weir has a long "divide" wall, parallel with the river bank, between the under-sluices and the lock and stretching diagonally more than half way across the river immediately below the two locks. This wall was part of the original design, and was constructed when the weir was built, but its length was increased some years afterwards. Its object was twofold: first, to keep a good channel open to the under-sluices by inducing a strong scour between the "divide" wall and the head-sluice; secondly, to keep a channel open between the two locks. It fulfils the first object, but it is at least doubtful whether it was necessary for that purpose. The silt in the river is fine and easily carried away, and it is most probable that the under-sluices would have effected their purpose without the "divide" wall. As regards



WEIRS ON DEEP HARD SAND.

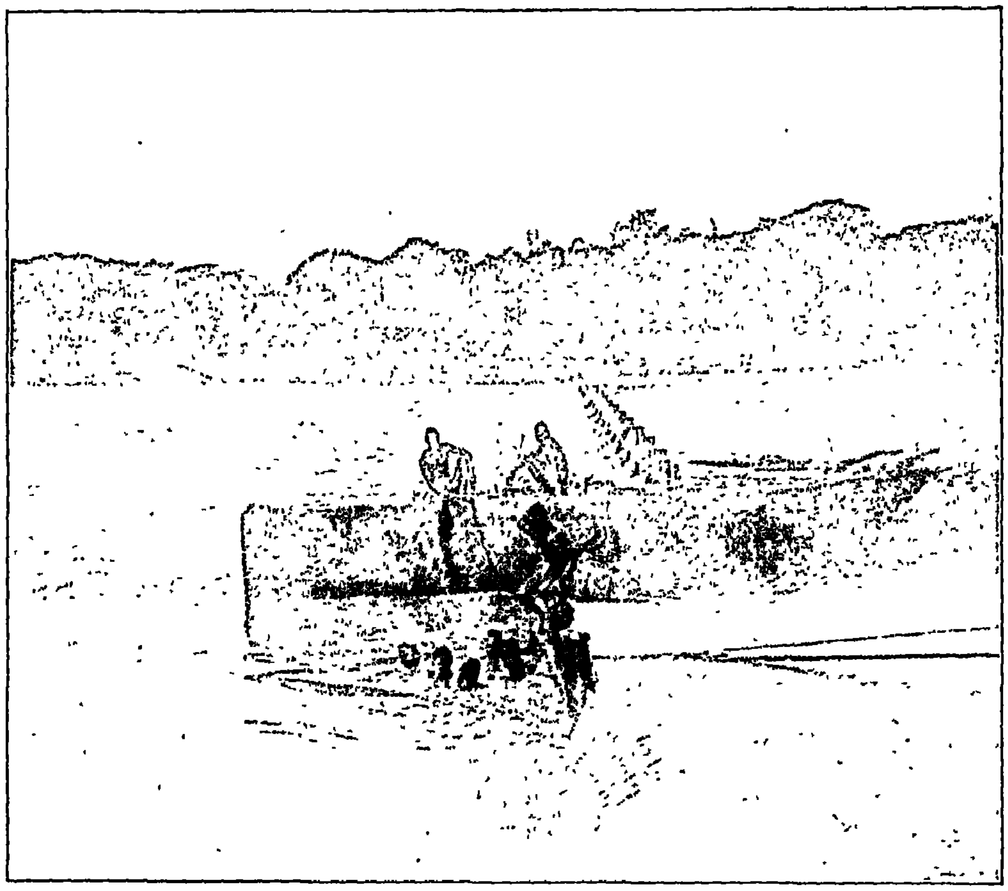
the second object, the wall has done no good; indeed, it has rather created a difficulty. The diagonal portion induces such a strong current in front of the lock on the east bank that it was soon found necessary to construct a timber jetty (not shown in the plan) on the down-stream side of the lock to prevent boats being swept down to the under-sluices. This jetty is fitted with shutters, sliding in grooves between the vertical piles, which are let down when the under-sluices are open, to check the current. When boats issue from the east lock they have to be towed up-stream, along the east bank, before they can be safely warped across the river. Unless the jetty protected them from the stream it would be most difficult to head them up the river as they issued from the lock into the current; as it is, they are frequently swept against the jetty. The open space between the nose of the "divide" wall and lock, on the west bank, keeps clear so long as there is a large discharge in the river, but it silts up as soon as the flood falls. It is necessary to dredge out a passage through the deposit into the deeper channel of the river, which the "divide" produces near the east bank. The lock channel immediately below the lock and the river bank can be kept clear by flushing, from the water in the canal, by the help of a flushing barge (see page 43), but the effect of this does not extend beyond the river bank.

Weirs of the fifth class, that is, those founded on hard sand of great depth, are more numerous in India than those of the other classes. Pure sand, next to rock itself, is the best foundation that a weir can have. It is hard, it is indestructible, it is incompressible. But there is this danger in a sand foundation: the sand is liable to be disturbed and carried away by running water. If sufficient protection can be afforded against any flow of water underneath the weir and against any excessive velocity over the bed of the river below it, the structure will stand secure. If materials are available, it is, in every case, only a question of time and money to make a weir across a bed of pure sand a certainty. The size of the stone used must be proportional to the velocity of the current: if only comparatively small stones are available the talus of the weir must be prolonged, so that, by decreasing the slope at which the pitching stands, it may have the less tendency to be displaced. The velocity of the water passing over a weir is greatest at the crest: it is at this point that the heaviest stones are required in a weir of dry stone. Usually the crest is laid in masonry; in that case, if the work be thoroughly well done, large stones are not essential, provided that the mortar itself is sufficiently good to stand the erosion. Thoroughly well-laid rubble masonry, or even boulder[1] masonry, will often stand successfully where ashlar masonry has failed.

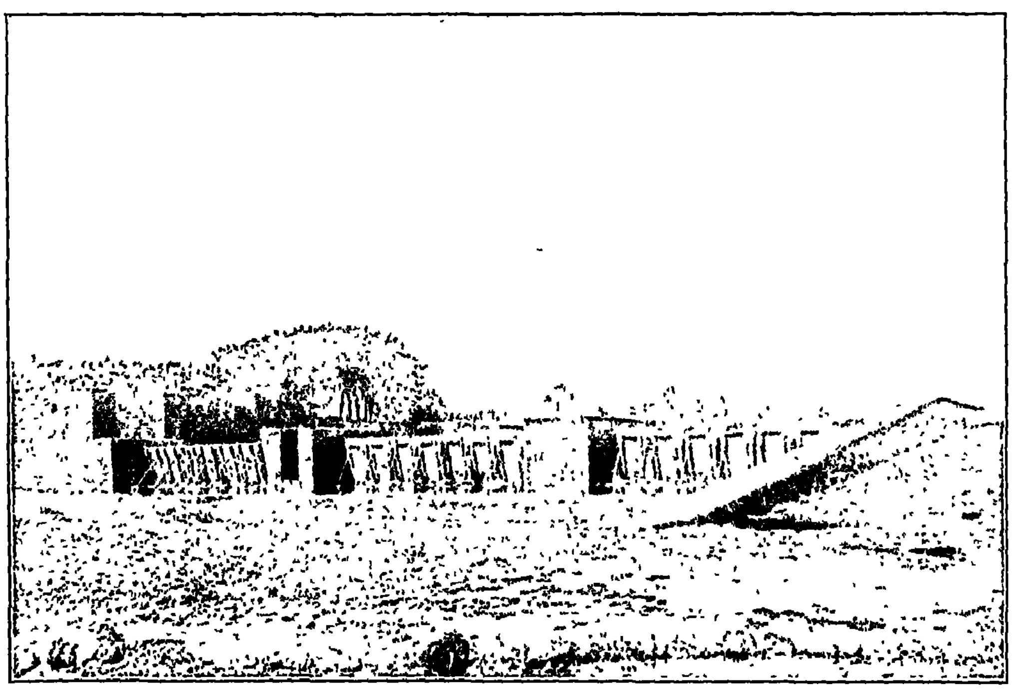
The weir across the river Kistna in Madras (Plate on page 145) claims first attention as one of the most remarkable of this class. It was built in 1854—55. The body of the weir itself is about 3,000 feet long, but the entire length of the weir including the under-sluices and piers is nearly 4,000 feet. The crest of the weir is 16 feet above the summer level of the river, and from 20 to 25 feet above the deepest parts of the original bed as it was before the weir was constructed. The river Kistna above and below the site of the weir is from $1\frac{1}{4}$ to $1\frac{1}{2}$ miles in width, but it narrows at the point where the weir is built to the dimensions given. A spur of sandstone runs down to the bank of the river at each side of the weir. The fall of the bed of the river above the weir is about 13 inches a mile; below it the slope is about 11 inches a mile. The ordinary greatest rise of the river in this gorge before the weir was built was 35 feet, and in extraordinary freshets as much as 38 feet has been recorded. The velocity of the river in freshets was as great as 10 feet a second before the construction of the weir; the velocity over it now is said to attain 16 feet a second, at which times there is a depth of as much as 20 feet over the crest.

The construction of a weir at this point was a bold enterprise, but it was successfully

[1] See pages 124 and 161.



Lifting Under-sluice Shutters, Panchkoorah Weir.



Under-sluices, Midnapore Weir.

[To face page 146.

accomplished. The bed of the river was very uneven on the line of the weir; the floods scoured out deep holes, sometimes on one side of the river, sometimes on the other. It was at one time intended to have filled up all the inequalities of the bed with stone, but sand was used for this purpose instead. On the bank of sand, thus thrown up in the deep parts of the river, wells were sunk to a depth of 7 feet below the summer level. On the top of the wells a heavy course of ashlar masonry 3 feet thick was laid. Above this a massive wall of rubble masonry, $13\frac{1}{2}$ feet high, 12 feet base, and 6 feet top, coped with ashlar, was built. Behind this wall a mass of rough stone of all sizes up to five and even six tons in weight was deposited. At 100 feet back from the main wall another one was constructed—the top of this was 6 feet below the crest of the weir: between the two walls the surface of the weir is packed with the largest stones placed on end; the interstices of these stones are filled as far as possible by quarry shivers jammed well into them. Behind this second wall the apron of the weir is continued for about another 100 feet with large stones.

This weir obstructs from three-sevenths to one-half of the former waterway of the river at the site where it is built, and although the action on the weir is consequently great, very little repairs have been needed since the work was first completed in 1855. Some stone has been added year by year, and on one occasion a short length of the body wall was torn away. The yearly repairs have averaged about $1\frac{1}{2}$ per cent. on the original cost.

The weir across the Godavery river at the head of its delta on the Madras coast (Plate on page 145) was constructed some years before the weir on the Kistna; although it has not the large sectional dimensions of that weir, it is one of the most remarkable in India. At the time when this work was undertaken, there was no weir in existence across a river of the width and capacity of the Godavery. This river issues from the hills at a distance of about 60 miles from the sea; between that point and the coast the fall of its bed is very irregular, it varies from 3 feet to as little as $4\frac{1}{2}$ inches in a mile, the average fall being between 5 inches and 6 inches. The rise of the floods at the point where the river issues into the plains is as much as 38 feet, and at the site of the weir the rise is 27 feet or 28 feet. The bed of the river is of pure sand. The Godavery weir is built in four sections, the united length of which is nearly 12,000 feet; three islands in the bed of the river divide these sections from each other. Across these islands earthen embankments are constructed aggregating more than 6,000 feet in length. These connect the four separate portions of the weir.

The Plate on page 145 shows the cross section of the first and second lengths of the weir: the other lengths are very similar in design. The original idea for the weir contemplated a vertical drop wall with an ashlar floor below, but this design was abandoned, in favour of that shown, in consequence of the difficulty in obtaining skilled workmen to execute it. The main wall of the weir is founded on circular wells which are 6 feet in diameter, and are sunk 6 feet in the bed of the river. The main wall itself is only 4 feet thick at the base, and 3 feet at the top. Over this there is a solid masonry flooring, 47 feet in width, of which 19 feet are horizontal, and 28 feet sloping and slightly curved in section. This floor terminates in another row of wells similar to those under the main wall. The masonry floor consists of 4 feet of masonry, covered with cut stone blocks strongly clamped together. Below the lower row of wells there is an apron of rough stone pitching which varies in width, but is generally about 70 feet or 80 feet. The body of the weir, between the two rows of wells, rests on a core of sand which was thrown into place, wetted and rammed. The second section of the weir is very similar to the first, with the exception that the front wall is founded on a mass of rough stone which extends under the body of the weir in the place occupied by sand in the first section. The apron is strengthened by a bar of masonry, 4 feet by 3 feet, which is carried longitudinally

through the length of this section of the weir. The third and fourth sections are generally similar to the first one; but the fourth section is rather stronger—the masonry is a few inches thicker, and the front slope is protected by a rough stone apron about 6 feet or 7 feet wide, which is carried along its entire length.

Another Madras weir, earlier in date than those which have been described, claims notice both on account of the fact that it was the first weir of considerable dimensions which was constructed in India by British engineers, and also because it shows how light a structure can be built across the bed of a sandy river. The weir across the Coleroon river in the Tanjore district was built in 1836, with the object of regulating the relative discharges of the Coleroon and Cauvery rivers, which bifurcate at the site of it (see Plate on the opposite page). The Coleroon river is 2,250 feet broad at this point; the fall of the bed is about $3\frac{1}{2}$ feet per mile. The freshets rise about 15 feet above the summer level of the river; the bed is of pure sand. As it was originally built the weir consisted simply of a rectangular bar of masonry stretching across the river bed. This bar was founded, on the up-stream side, on a double line of wells sunk 6 feet into the sandy bed of the river, and, on the down-stream side, by a single line of similar wells. Above these was a masonry floor 27 feet broad by only 3 feet thick, 2 feet of this being brick masonry; and the upper foot, below the weir wall, was ashlar masonry carefully laid. The weir wall itself was rectangular in section: it was 6 feet broad throughout and 7 feet 4 inches high in the northern section of the weir, and 5 feet 4 inches in the two other portions; the weir was divided by two small islands into three separate lengths. Below this bar of masonry there was a rough stone apron only 9 to 12 feet broad by 4 feet deep. The weir wall was cut through by twenty-two sluices 2 feet broad by 3 feet 6 inches high; these were placed at intervals along the weir.

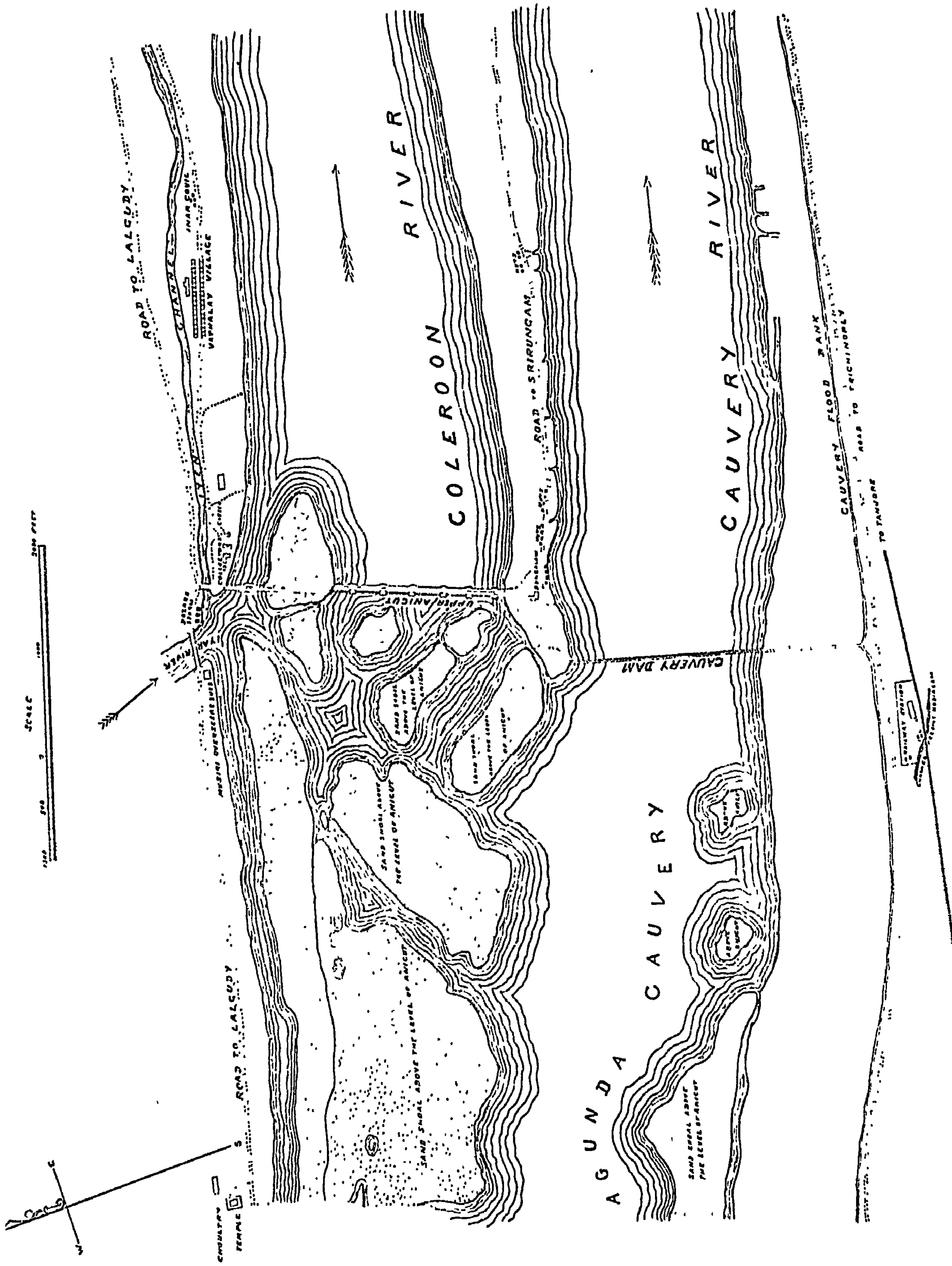
This structure was an extremely light one, especially as regards the width and thickness of the floor and of the pitching below it. An accident did occur to the weir the season after it was completed; a length of about 240 feet of it was swept away. This accident was caused by the leakage of water below the weir wall, which undermined the foundations; the water, before the weir gave way, could be seen bubbling up in many places through the apron below the weir whenever there was a head of 5 or 6 feet of water on it. The weir was repaired immediately after this accident and was materially strengthened, and from time to time the rough stone apron has been increased as occasion demanded; but it has been proved that this weir, weak as it is, is a sufficiently strong one in this particular case. Typical sections of it are given in the Plate on page 145.

In spite of the several[1] alterations and improvements to the Upper Anicut, it was found in the course of time, that the bed level of the Cauvery was being raised. By building what practically amounted to a solid dam across the Coleroon, all the sand and silt transported by the river was being sent down the Cauvery and there deposited. The crest, moreover, of the *anicut* was no longer high enough to send a full supply of water down the Cauvery, as the quantity required had increased considerably, while in times of flood the weir made it difficult to get rid of the surplus.

It was therefore decided to remodel the *anicut* entirely. The work was begun in 1899 and finished in 1904, at a cost of about Rs. 6,58,000.

The new *anicut* is built on the up-stream side of the old one. The old flooring is thus utilised in protecting the down-stream side of the structure. To prevent scour underneath the *anicut*, a line of wells was sunk on the up-stream side to a depth of 16 feet below apron level. This is 2 feet higher than that of the old apron, and a drop of this height occurs just below the

[1] Note by Mr. A. H. Morin, Executive Engineer, Tanjore Division.



WEIRS ACROSS THE COLEROON IN TANJORE.

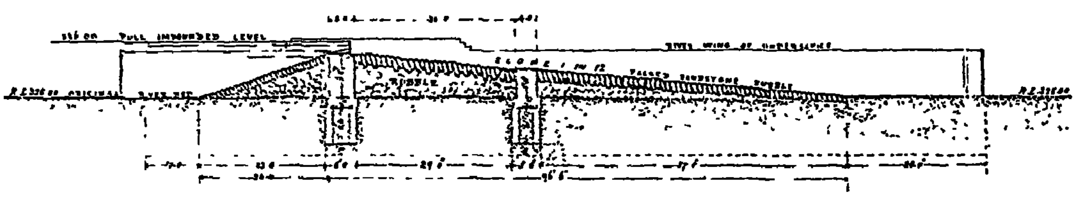
down-stream side of the new *anicut*. The new apron, like the old one, is 3 feet thick, faced with granite on the upper surface.

The *anicut*, as rebuilt, consists of two sections separated by an island, one with ten bays and the other with forty-five, each of 40 feet span. The *anicut* is, in fact, an arched bridge, the water passing through it being regulated by means of lift shutters. The total length between abutments is 463 feet in one section and 2,064 feet in the other. The sill of the new *anicut* is 4 feet below the crest of the old weir, the top of the shutter being thus 2 feet higher than the latter.

The lift shutters, which are 6 feet high and 40 feet span, weigh eight tons; they are counterbalanced and so geared that they can easily be manipulated by hand. The bending stress on the face of the shutters is resisted by two bowstring girders placed horizontally behind it. (See sketch, page 195.)

The shutters are fitted with rollers, two pairs on either side, which move up and down on a vertical steel path. When completely down, the lower edge of the shutter is in contact with a sill girder let into the flooring and makes a fairly tight joint. Leakage of water at the sides is prevented by a curved flexible plate which is pressed over the clearance space by the pressure of the water.

The head-works of the Sone Canals in the district of Behar in Bengal are shown on the Plate opposite this page. The bed of the river is deep sand with occasional layers of small



SECTION OF THE SONE WEIR, 12,469 FEET LONG.

pebbles. The river has its source in the plateau of Central India, and joins the Ganges near Patna, after a course of 325 miles, mostly through the rocky region at the base of the Kymore Hills. After it leaves the hills, the river, in the last 100 miles or so of its course, assumes a deltaic character, which is very marked in the immediate vicinity of the Ganges.[1] The drainage area of the river is about 23,000 square miles; its maximum discharge is 830,000 cubic feet a second, and the minimum in the hot weather has fallen to 450 cubic feet. The maximum rise in the river flood at the site of the head-works is 15 feet above the summer level. The fall in the bed of the river after it emerges from the hills gradually decreases from 2·7 feet to 1·7 feet in the mile, and the width and cross section of the river decrease in the lower reaches near the Ganges. The head-works of the Sone Canals are situated at Dehree, about 25 miles below the point where the river leaves the hilly ground and about 40 miles above the point where it spills over its banks on occasions of high floods.

The weir across the Sone is believed to be the longest in one unbroken piece of masonry which has been constructed; the length between abutments is 12,469 feet. The weir consists of two parallel walls 30 feet apart, founded on rectangular wells 10 feet by 6 feet, sunk generally to 8 feet below the original bed level and filled with concrete; some few of the wells were sunk to 10 feet. Between these walls the weir is hand-packed with large rubble stone at a slope of 1 in 12, and this packing is continued below the lower wall at the same slope down to the bed of the river. The up-stream slope above the upper wall is smaller rubble packed at a slope of

[1] See page 103.

1 in 3. About 2,000 feet below the weir is the Sone causeway, which was constructed, long before the weir, to carry the grand trunk road across the river; it is now a continuous piece of masonry across the whole width of the river. There is no probability of any retrogression of levels in the bed of the river below the weir; but, if there were any danger of this, the causeway might easily be made a powerful defence to the weir. The weir was originally pierced by three sets of scouring sluices. There was one set of 16 vents of 20 feet 7 inches in the centre, and there is one set on each flank consisting of 20 vents of 20 feet 7 inches, just below the head-sluices of the canals.

The set of sluices in the centre of the weir existed for nearly thirty years, but have recently been closed. It was a matter of discussion, when the weir was originally designed, whether these centre sluices should be constructed or not. It was argued: first, that they would tend to keep a navigable channel open across the river: that they have failed to do. Secondly, it was said that they would at least tend to prevent the accumulations of sand above the weir: this, too, they failed to do except in their immediate vicinity. Thirdly, it was said that they would, in floods, fill up the river channel, below the weir, more quickly, and thus protect the talus of the weir by a water cushion: this function they undoubtedly did fulfil to a certain extent. Since they have been closed, it has been found necessary to repair the toe of the down-stream slope of the weir slightly more than in previous years, but only to a small extent. The experience gained in the use of these centre sluices was that they required more or less frequent manipulation in the flood season in order to keep up the level of the pool above the weir. This manipulation was most troublesome and sometimes dangerous: the men had to travel over a mile, either on the weir itself, or in a boat, to reach them. This, in bad weather, or when a flood was possible, was laborious and sometimes a matter of some risk. One result was that the centre sluices were often left open when they should have been closed, with bad effects on the canal discharge. Another result was that the channels maintained to the heads of the canals, on either bank of the river, were not scoured as much as they needed to be, in some years, as a considerable volume of water passed through the centre sluices which might have been used to scour the other channels. The repairs to the centre sluices were heavy, and it was an economy to close them. They were, accordingly, built up in 1901 at a cost of Rs. 16,000, as shown in the sketch on the next page.

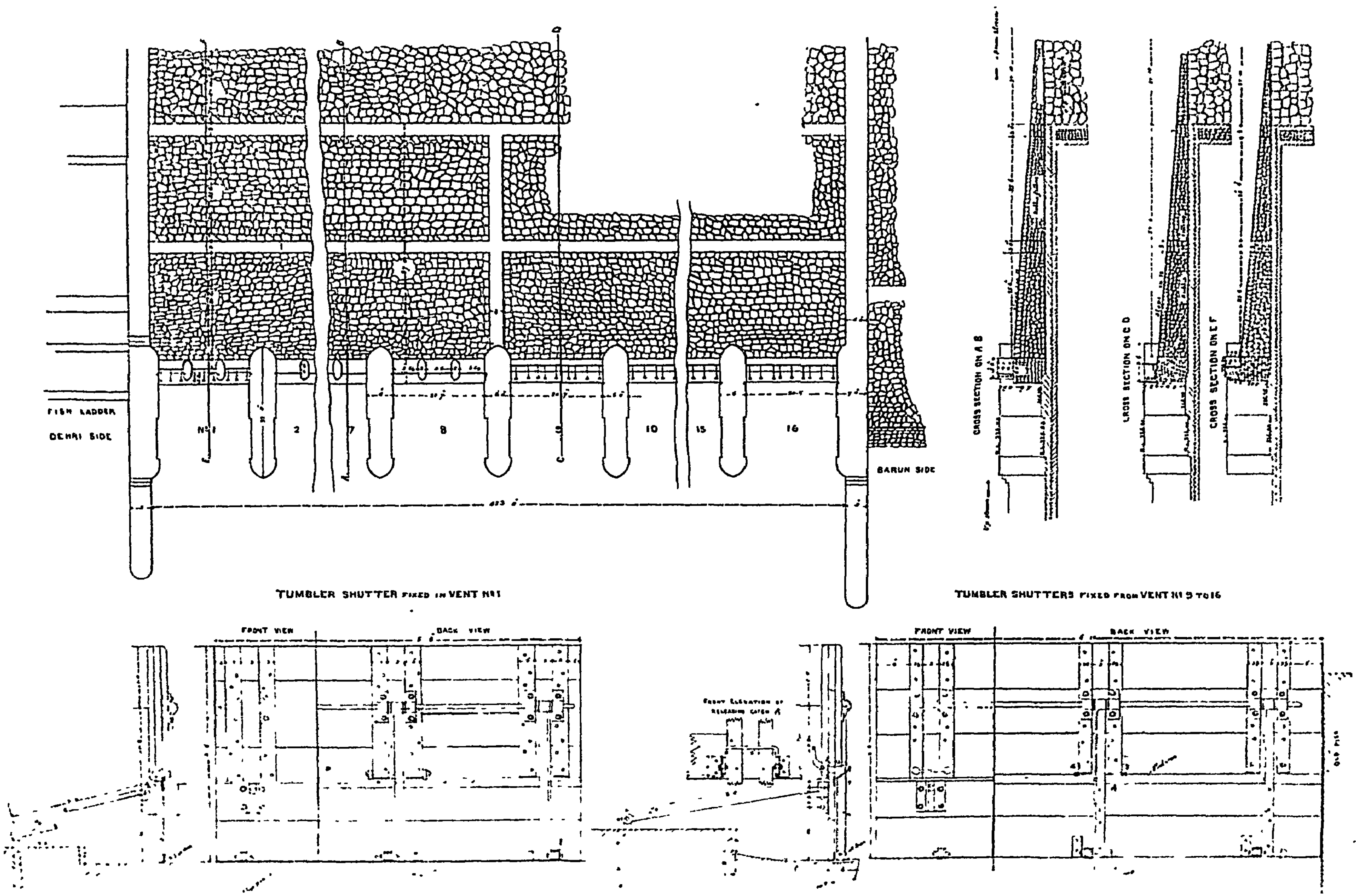
The crest of the vents was fixed a few inches lower than the crest of the main weir (which has 2-feet shutters along its whole length), and double tumbler shutters were fitted as shown in the Plate. These are an improvement on the original design shown on page 191.

Each of these shutters,[1] as now made, consists of two parts, the lower part being about one-third the total height of the shutter. Bolted to this is an angle iron piece to which the upper part of the shutter is hinged at about the middle. To the lower part of the shutter, at about the centre of pressure for the whole shutter, are fixed three tension rods, to which the shutter is hinged, the up-stream ends being fastened to eye-bolts in the breast-wall.

At the centre of the shutter, longitudinally, a catch is fixed which engages the lower part of the shutter and keeps the two parts together when the shutter drops, and prevents it from rising in a camel's back, as was the case in the original design, the catch being kept closed by the force of the water against the handle.

The shutters are lifted from the front. Iron rods are hooked into catches placed between the vertical battens at the lower end of the upper part of the shutter and the handle of the catch, which is thus released. The upper part is then pulled up, presenting only the edge to the water, which, acting on the lower part, brings the shutter to a vertical position. The

[1] Paper on the Sone Canal Head-works, by Mr. G. C. Stawell, 1904

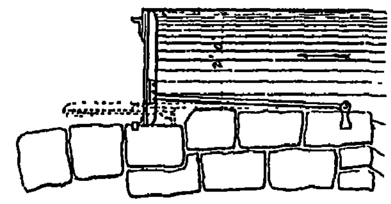


PERMANENT CLOSURE OF THE CENTRE SLUICES OF THE SONE WEIR.

shutters used are 6 feet 10 inches long and 3 feet 6 inches high, and can easily be lifted by four men against a head of 2½ feet.

There is an objection to them, in that some means are required to admit of men getting on the up-stream side unless piers can be built. They are also liable to be damaged, unless protected in some way or sunk a good deal in the weir wall, by trees and brushwood being brought down the river in flood. Some have suffered in this way, but they may, on the whole, be considered as having been a success.

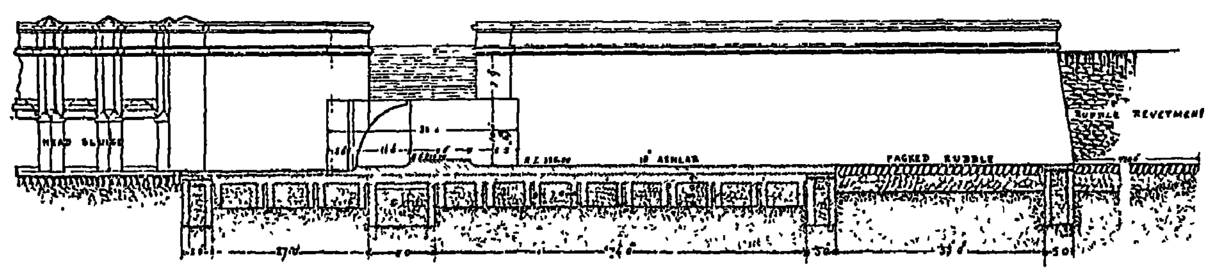
The closure of the under-sluices is said to have made it more difficult to keep a still pool above the head-sluices of the canals; for, at certain periods of the flood, it is necessary to keep some under-sluice vents open which might have been closed if the centre sluices had been available.



CREST SHUTTERS OF THE SONE WEIR.

The original level of the river bed was about 326·00; the crest of the weir is 334·00, or 8 feet above the original bed. The under-sluice and the centre sluice floors are at 326·00 (but immediately between the piers there is a short length 9 inches higher between the shutters), and the tops of the under-sluice piers are 336·00. The highest flood is rather more than 8 feet above the weir crest. The weir obstructs about one-half of the former waterway of the river, but the afflux has been calculated to be only about 15 inches; there is no spill over the banks above the weir, and there are no marginal embankments nor protective works of any kind. The banks of the river are of hard soil with some kunker[1] mixed with it. The floor of the head-sluices on each bank of the river is 326·00, the same as the under-sluice floor, or 9 inches below the step in the under-sluice floor between the shutters.

The crest of the weir is fitted throughout its entire length with small iron shutters. Each shutter is 18 feet long by 2 feet 3 inches high, of light plate-iron stiffened with angle-irons. The shutters are hinged to tie-rods 4 feet long, which are capable of oscillating at their up-stream end on a horizontal pin attached by a rag-bolt to the crest of the weir. The point at which the tie-rods are hinged to the shutters is about 3 inches below the centre of pressure



SECTION OF THE UNDER-SLUICES OF THE SONE WEIR.

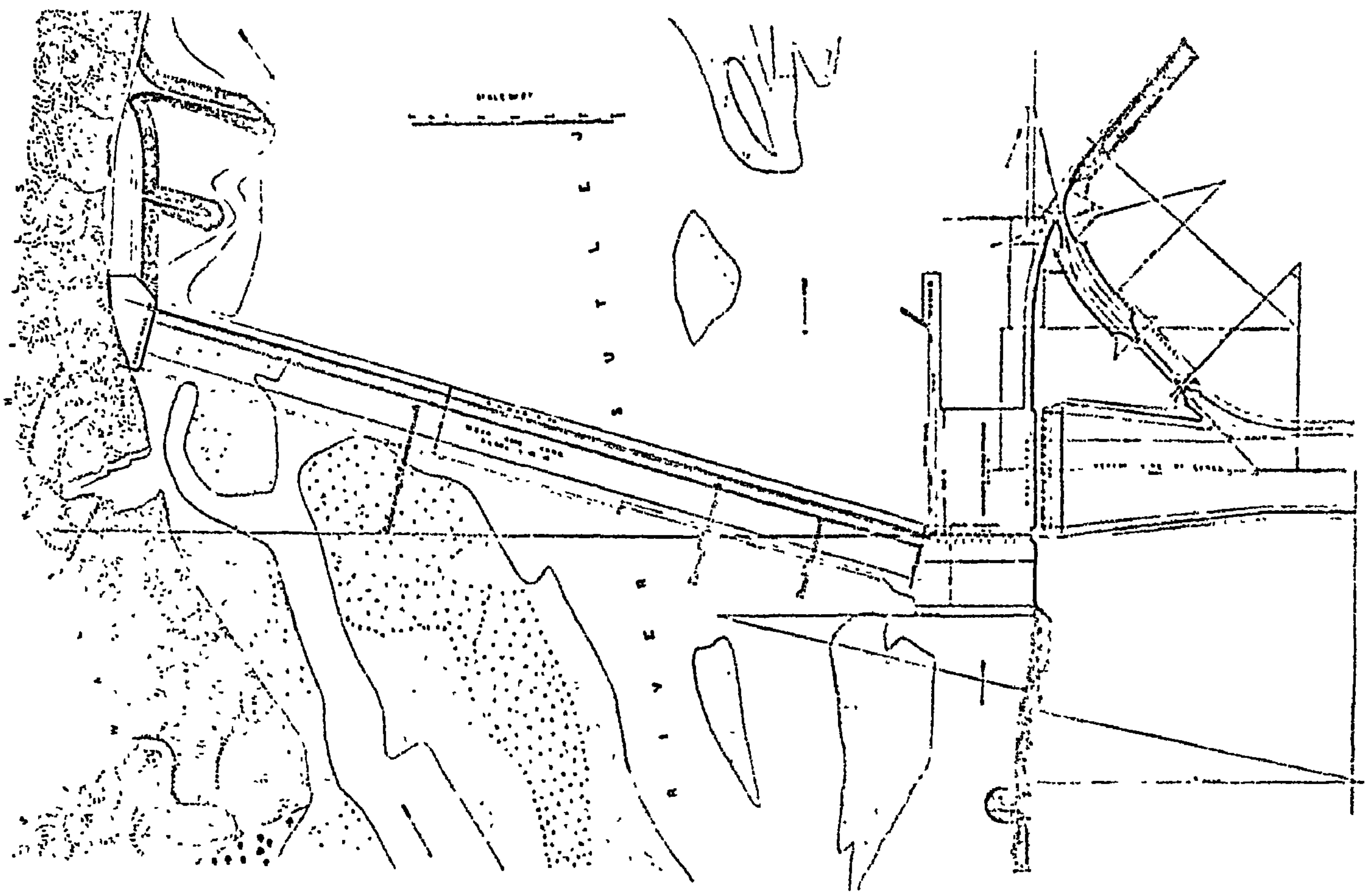
of the water when level with the top of the shutters; the shutters are, therefore, on the point of overturning when the water is at that level, and will overturn and fall into the recess provided for them when the water rises higher. They sometimes remain in that position all the flood season, and are raised after the floods by hand. Four men can raise these shutters, when a depth of 6 inches or 8 inches of water is flowing over the crest of the weir, almost as quickly as they can walk. Shutters on this principle have been adopted in many weirs.

The shutters of the under-sluices are unique: they consist, first, of an upper shutter

[1] Nodular limestone.

20 feet 7 inches long, by 10 feet in height, hinged to the floor at its lower edge, and fitted with hydraulic brakes behind; and, secondly, of a lower shutter which is hinged to the floor by connecting-rods. The upper shutter is used to close the vents, and the lower one is used to retain the water and to open the vents; a detailed description of these gates is given in Chapter XI.

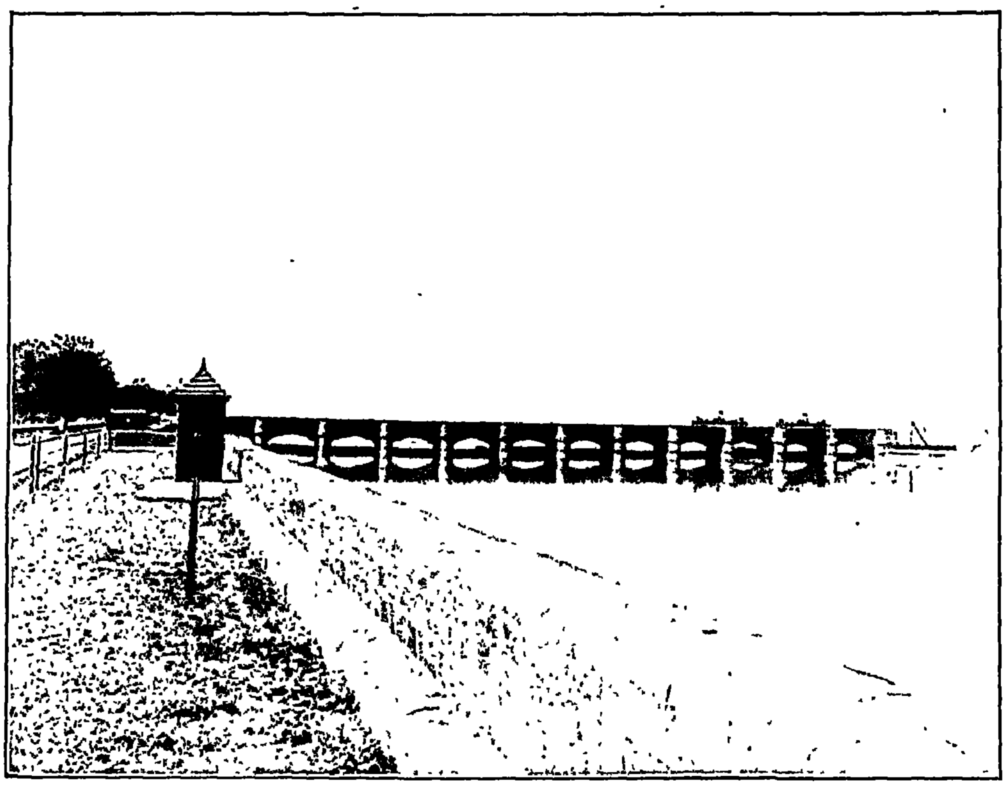
The under-sluice piers and the entire floor of the under-sluices, which is 537 feet by 123 feet, are founded on rectangular blocks or wells generally 8 feet square, which are sunk, all over the entire area, to a depth of about 8 feet: the blocks under the piers are longer and deeper. The



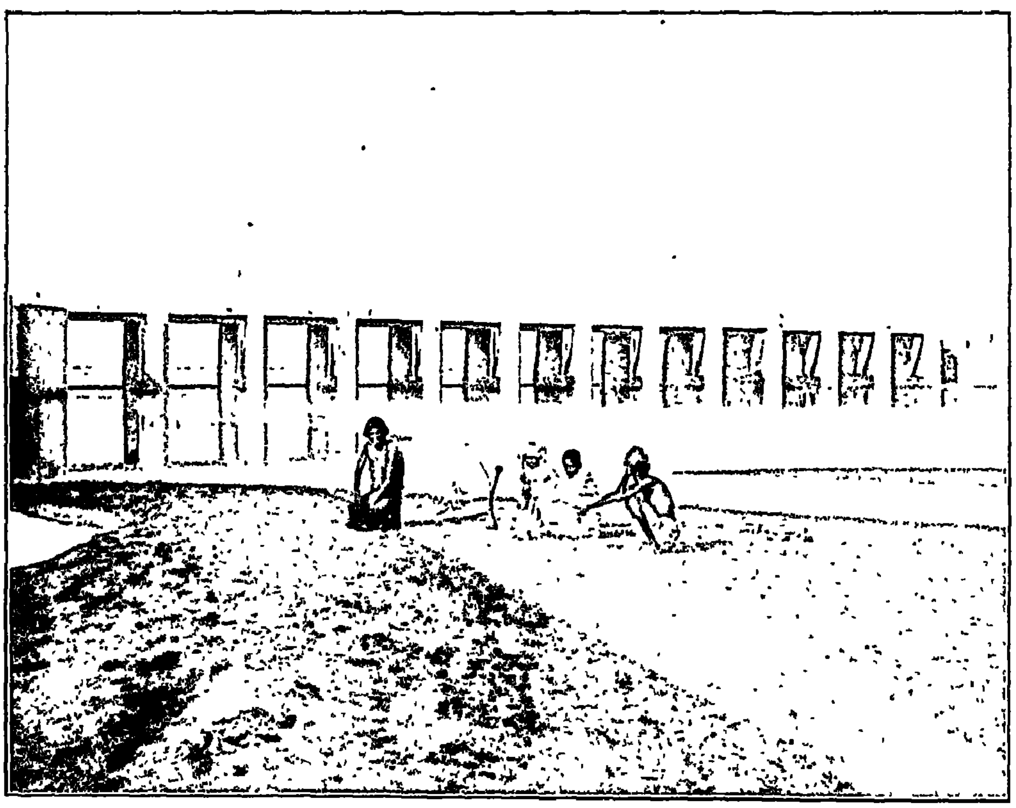
HEAD-WORKS, SIRHIND CANAL.

wells are filled with concrete and covered with masonry topped with ashlar 18 inches thick. The under-sluice piers are not carried above high flood level, but are entirely submerged in flood; the crest of the pier is only 336·00, a high flood being over 342·000. The piers, which are of ashlar, were at first built only 4½ feet thick, but this was found to be insufficient, as some of them were overthrown sideways in a heavy flood, and they were reconstructed 6 feet thick, and strongly bound together by iron through bolts. The upsetting of the original piers was extraordinary, and has not been satisfactorily explained; five or six of them were upset together sideways, as though some force at right angles to the direction of the current had attacked them.

The Sirhind Canal in the Punjab is supplied from the Sutlej river at Rupar. The bed of the river has a slope of about 2 feet a mile, and is composed of sand, with underlying shingle and boulders of moderate size. The minimum discharge of the river at this point is 2,800 cubic feet



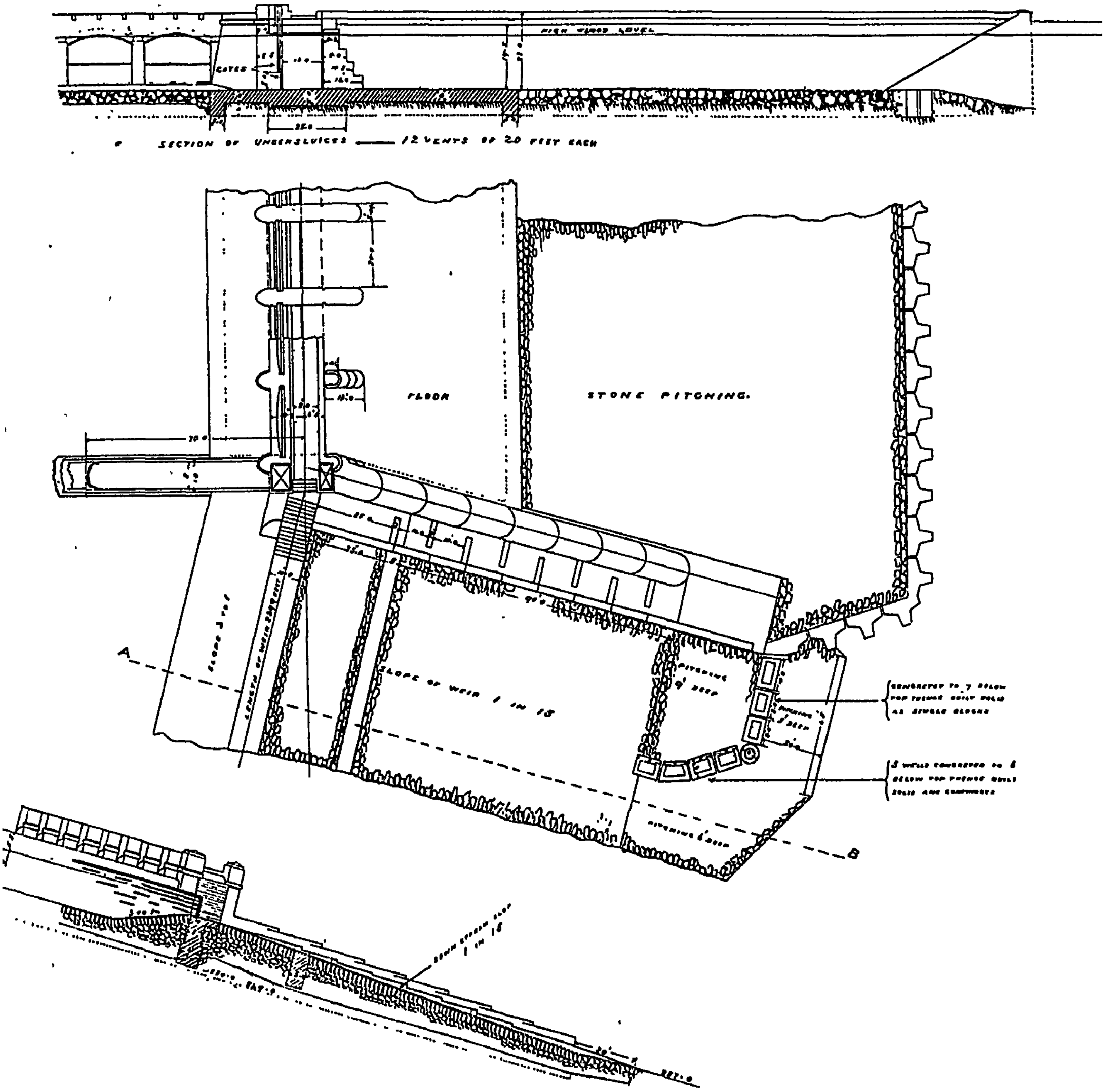
Under-sluices of the Rupar Weir at the Head of the Sirhind Canal.



Under-sluices of the Jhelum Weir.

[To face page 154.

and the maximum 133,000 cubic feet a second. The lowest summer level of the river is 857·8 above mean sea, and the highest flood, before the construction of the weir, was 873·35. The river commences to rise early in May, from the melting of the snows: the highest floods are at the end of July; by October the river has fallen to nearly its lowest levels. There are no

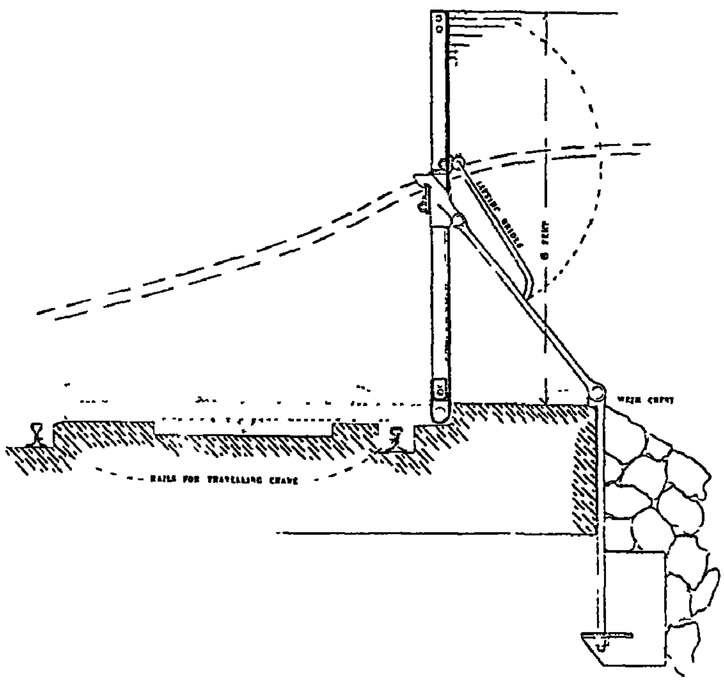


WEIR AND UNDER-SLUICES OF THE SIRHIND CANAL ON THE SUTLEJ.

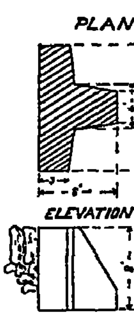
great fluctuations between October and May; freshets are very frequent in July, August, and September. The highest flood on record rose 5½ feet in three hours, remained at full height for four hours, and then gradually subsided in ten days to the normal level of the river at the time. A plan of the head-works is given on page 154.

The under-sluices of the Rupar weir are at right angles to the stream, but the weir inclines

up-stream from the sluices at an angle of 15 degrees. The right flank of the weir consists of a revetment wall 350 feet long, the ends of which are set into the high cliffs which form that bank of the river. The weir proper is 2,400 feet long: its crest was originally built at 865·00, or 8 feet above the general level of the river bed; but it has since been raised, and falling shutters, 6 feet in height, as shown in the sketch, have been erected along it. The weir consists of two walls, the upper one founded 7 feet and the lower one 3 feet below the ordinary river bed. The up-stream slope of the weir is 1 in 3, and the lower slope 1 in 15. The under-sluice floor is 100 feet broad, 5 feet thick under the superstructure, and 4 feet elsewhere. The pitching below the floor is very heavy, each stone weighing as much as 30 cwt.: this pitching is partly laid in mortar. The under-sluices consist of twelve openings of 20 feet each, with draw-gates lifted by a winch travelling on rails above. At the toe of the stone pitching below the under-sluice floor, masonry blocks 12 feet by 8 feet are built as shown in the sketch. There was, at one time, some pooling down-stream of the under-sluices to a depth of 20 feet below the level of the river bed, but the slope of the pool from the toe of pitching was gentle, and there was no tendency to undermine the floor. The head-sluice or regulating bridge consists of thirteen bridge spans of 21 feet each. The head-sluice gates are of iron as sketched on page 40. The floor of the head-sluice is 2 feet above the under-sluice floor, and there is a breast-wall 7 feet high above the floor. The supply of the canal is drawn into the canal, in all cases, at or above the level of the crest of the breast-wall.



CREST SHUTTERS ON THE RUPAR WEIR, SIRHIND CANAL.



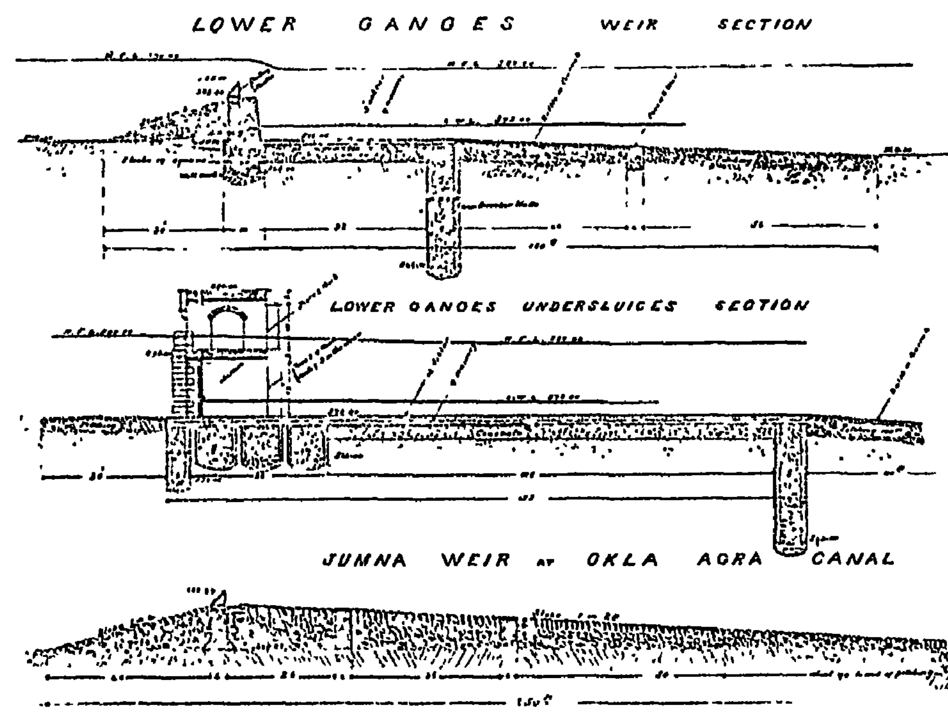
PITCHING BLOCKS, SIRHIND CANAL.

CHAPTER X.

HEAD-WORKS IN FINE SAND AND SANDY MUD.

Weirs in Fine Micaceous Sand—Narora Weir across the Ganges—Protective Works above the Narora Weir—Narora Under-sluices—Under-sluice Gates of the Narora Weir—Head-sluice, Lower Ganges Canal—Scouring Escape, Lower Ganges Canal—Head-works, Chenab Canal—Chenab Weir—Rosetta Weir—Chenab Under-sluices—Head-works of the Jhelum Canal—Jhelum Weir—Under-sluices of the Jhelum Weir—Okla Weir of the Agra Canal—Under-sluices, Okla Weir—Protective Works, Okla Weir—Comparison of Deep and Shallow Foundations—Percolation below Weirs—Barrage across the Nile below Cairo—Reconstruction of the Nile Barrage—Zifta and Assiut Barrages—Cost of Indian Head-works.

THE weirs which form the head-works of the Agra Canal and the Lower Ganges Canal are both constructed in micaceous sand almost as fine as flour. The Agra Canal weir is on the Jumna at Okla, and the Lower Ganges weir is on the Ganges at Narora. The following sketch shows the two weirs, which differ greatly in design:—



SECTIONS OF THE NARORA WEIR ON THE GANGES AND THE OKLA WEIR ON THE JUMNA RIVER.

The Okla weir is constructed on the surface of the river bed, with no foundations below that level, while the Narora weir has rectangular block and circular well foundations, which are sunk to depths varying from 7 feet to 30 feet below the river bed. The left bank of the Ganges at the site of the Narora weir is formed of very light friable soil, and the other bank is high and formed of red sand and clay: one bank of the Jumna at the Okla head-works is very light soil, but the other bank, where the Agra Canal takes off, is in rock. It was the existence of stone at Okla and the absence of all stone within any practicable distance of Narora which led to the difference in the two designs. The Okla weir is built of stone and the Narora weir of brick.

The sketch on the next page shows the site of the weir across the Ganges at Narora. The exceedingly friable nature of the soil on the left bank rendered it necessary to protect the weir against any erosion of the banks above it which might be caused by the increased height of the flood. The river immediately above the weir runs on its right bank close under the high land of the *bhangar*, which is chiefly composed of strong clay, but on the left bank the *khadir* land extends for some 12 or 14 miles before the high lands of the *bhangar* are again